Technology Review

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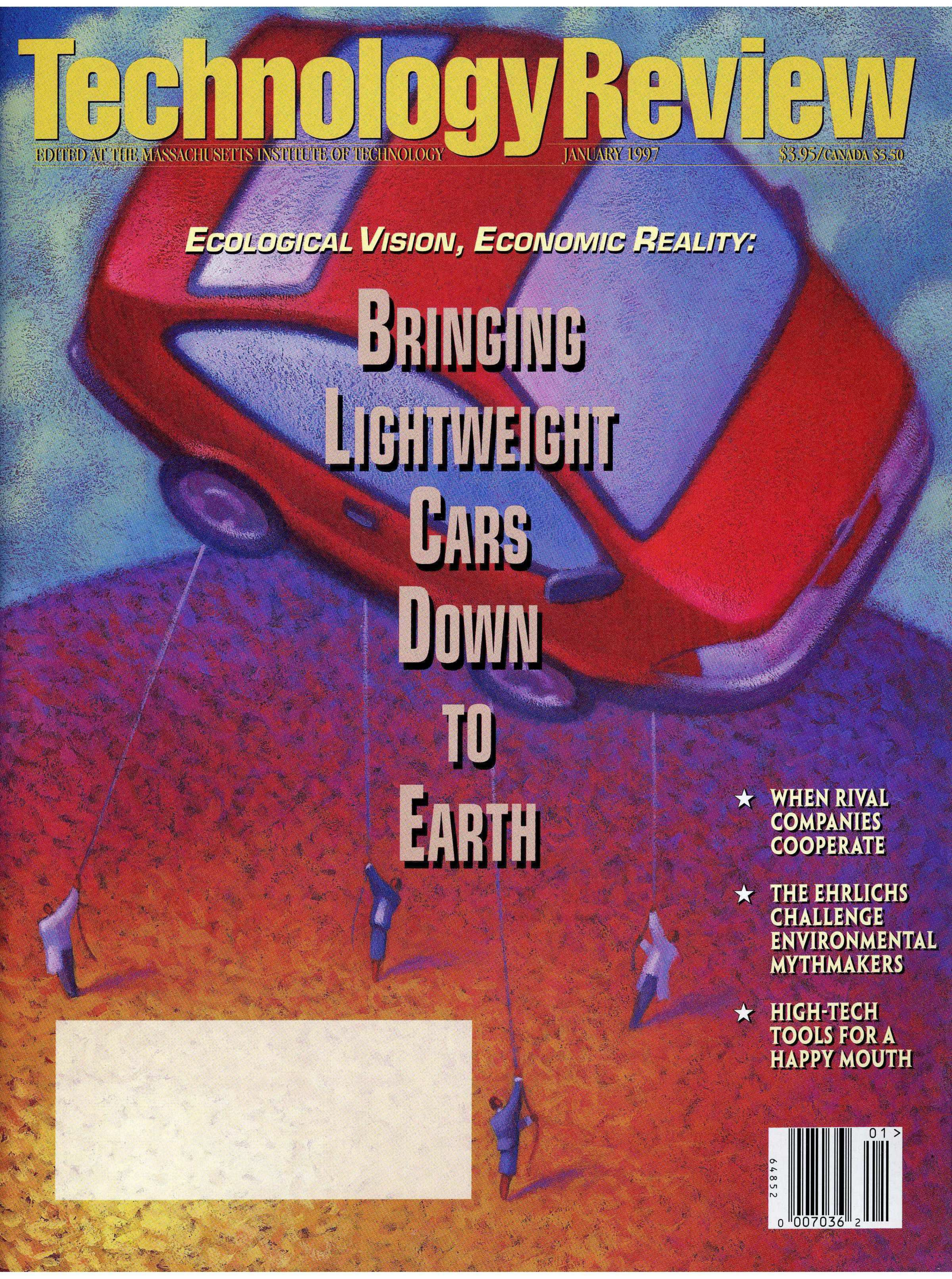

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- THE EHRLICHS CHALLENGE ENVIRONMENTAL MYTHMAKERS
- HIGH-TECH TOOLS FOR A HAPPY MOUTH


Pam Jones is a chemical engineer, mother of two, nature lover and part of a team that pioneered a revolutionary regeneration process called Petretec℠. It takes used polyester plastic, unzips the molecules and allows it to be reused, good as new. An everyday jar can become a videotape, then a seat belt, then a designer shirt. "Evergreen polyester," Pam says, "the cycle continues on and on."
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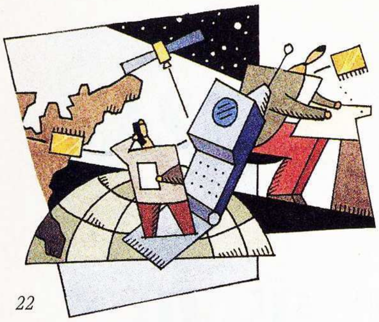

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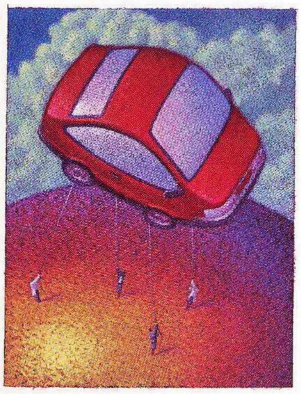

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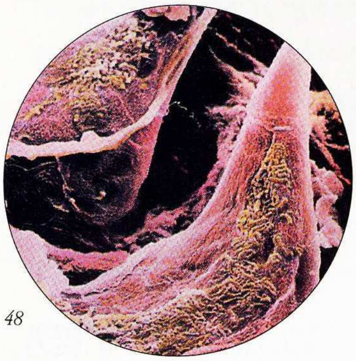

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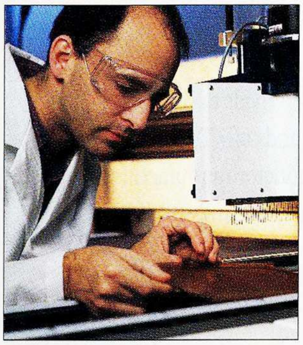
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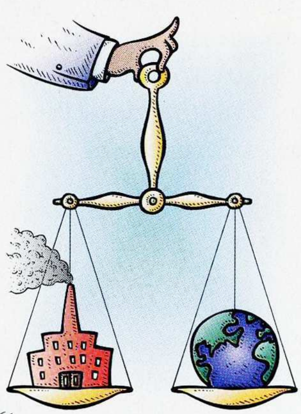
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First Line

Something to Sing About

TR's home page on the World Wide Web does what others don't.

A magazine article, given the inexorable limits on space, is necessarily just an appetizer. Readers who wish to pursue the article's subject more thoroughly have to look elsewhere. In the old days, all that editors could do to help in such quests was to offer a list of recommended readings—better than nothing, but still a bit of a chore for the searchers, and with gratification well deferred. They'd have to hunt down the leads themselves, possibly consulting numerous libraries or bookstores, and the more obscure sources might be virtually unobtainable.

With the World Wide Web, such followup to other sources of information should be as easy as the click of a mouse. Problem is, although many magazines have elaborate Web sites, they are of limited value for the intellectually curious reader who wants to go further and deeper on the theme of the article. Most of these links, as Bob Dole might have said last fall, "just don't do it."

Some magazines put many of their articles online but with few links, so readers are basically perusing a full-length article, just as in print, but at the discomfort of their computers. Occasionally, articles do include numerous links, but they are usually peppered throughout the text, making a hard-to-read format even harder.

In addition, such links pose several inherent problems. Each is represented by only a highlighted word or a short phrase so it doesn't interrupt the text. But that means what it serves up will essentially be a surprise to the reader. And many of these in-text links are not so much explorations of the subject at hand but footnotes or asides, with source and context of the material often unidentified. In fact, these links are often off the subject altogether. If the text reads, for example, that Loretta Castorini of <u>Caltech</u> or <u>General Motors</u> or the U.S. <u>Environmental Protection Agency</u> said such-and-such about automotive air pollution, the link is to the organization's home page, which will glowingly tell you about the institute's course offerings, or the company's products, or the agency's diverse programs, but not, without a fair amount of effort and luck on your part, about the work and views referred to in the article.

Such pseudoconnections do exactly what the Web shouldn't do: take searchers away from rather than toward the information they seek. But that doesn't happen at *Technology Review*'s Web site. Thanks largely to the tireless efforts of director of marketing and circulation Martha Connors and senior editor Faith Hruby, the links to *TR* articles provide readers with detailed information on the actual subject of an article, not loosely related fragments or unrelated diversions.

Occasionally, we too will place a link in the article's text—when the absolutely right word is there, and when readers may be ready for a sidetrip—but we prefer to present our links all at once on an attached Web page. There we can describe each link—what it offers, who wrote it, where it has been published—so that searchers have some idea where they might be going. And readers can scan the whole set in order to make the best selections, confident that a link from Ms. Castorini will take them right to her particular material on automotive air pollution and not to her organization's home page—from which a circuitous, perhaps fruitless, cybersearch might ensue.

We develop Web links from our latest issue after it has been sent to the printer, so I cannot cite examples from the magazine you now hold in your hands. Consider, however, a few of the links from the previous (November/December) issue. Readers inspired by Robert Zubrin's "Mars on a Shoestring" can connect directly to the author's organization, Mars Direct, to tap into a wide variety of documents and images detailing his proposed mission, and from there to other organizations founded by Mars aficionados. Readers can pursue "Robots on All Twos" with links to the project's chief researcher, his Leg Laboratory at MIT, and connections to similar work elsewhere—for example, a treatise on robotic leg design from the Microprocessor-Controlled Autonomous Modular Walking-Vehicle Project at the University of Waterloo. And links from "Houses of Straw" can provide you with everything you always wanted to know but were afraid to ask about this ubiquitous but still exotic construction material. "If I wanted to build a strawbale house, all that I'd need is on the Web," says Hruby. "And we have linked to a rich array of what's available."

Similarly, by delving into *TR*'s archive of past issues, readers can go straight to expertise "down under" on sophisticated videoconferencing systems that connect remote aborigine communities in rural Australia (April 1996); learn more about, and even join, innovative "waste exchanges" that turn otherwise polluting materials into commodities (August/September); and follow up on an interview with World Wide Web creator Tim Berners-Lee by linking to a formidable collection of his writings (July).

Our commitment to supplying meaty, in-the-spirit-of-the-Web, and otherwise-hard-to-find links not only serves readers wishing to go further and deeper but also reflects the magazine's tradition of presenting high-quality information and diverse ideas. Of course, the motivation for all this "added value," as Connors puts it, is not entirely altruistic. "If people know that *Technology Review* will be a resource, we'll become a 'bookmark' for them, and they'll return again and again."

As proof that our approach is working, the Point Survey, a service that reviews Web sites, has named *Technology Review* to its much-coveted "top 5 percent of all sites on the Internet"—the result of our high numerical ratings on the survey's three criteria of content, presentation, and quality of user experience. "If scores could talk," says Point's literature, *TR*'s would "sound like the singing of Caruso."■

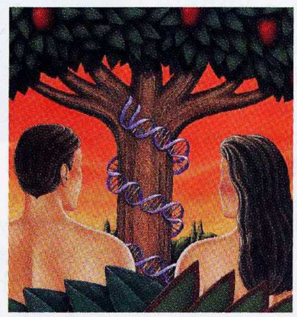
—Steven J. Marcus

P.S. Our URL is web.mit.edu/techreview/

Letters

Important Reminder or Red Herring?

Garland Allen does *Technology Review*'s readers a splendid service in "Science Misapplied: The Eugenics Age Revisited" (*TR August/September 1996*) by reminding us that Americans were no strangers to the ideas and policies of eugenics that were so destructively applied in Nazi Germany. One study of U.S. science textbooks from this period found that more than 90 percent presented eugenics as legitimate science. More than 75 percent recommended "positive eugenics" (marrying the best with the best) while 50 percent advocated negative eugenics (segregation and sterilization of those deemed least fit). Of course, these are the kinds of programs that were instituted to the extreme in Nazi Germany. Unfortunately, the social attitudes that informed that movement are still alive. As one of my friends confided after reading *The Bell Curve*, "You know, the book is a little extreme, but don't you think the basic idea is correct?" With today's popular press implying that many of society's problems are determined by our genes, Allen's is an important reminder and a serious warning.



Steven Selden
Department of Education Policy, Planning, and Administration
University of Maryland
College Park, Md.

Allen correctly notes that "the publicity given to each new or preliminary report on the genetics of human behavioral traits has grown faster than the research itself." Geneticists repeatedly make extravagant claims that molecular bases for schizophrenia, manic depression, and intelligence have been discovered—only to see subsequent studies fail to confirm the original reports. Nevertheless, each new claim receives front-page and top-of-the-hour news coverage. Retractions—if they make it outside of scientific journals—are relegated to the back pages.

Competition for research funding—and the perquisites that come with it—have taught many American scientists to spin the news media with the same unprincipled cynicism employed by politicians. Scientists now routinely announce "breakthroughs" at press conferences before any publication of research details or peer criticism. This was unheard of some years ago. And it is no longer only individual scientists who rush to the media. The National Institutes of Health, competing with the National Aeronautics and Space Administration (NASA) for federal money, now holds press conferences to trumpet the discovery of genetic bases (and imminent cures) for all manner of disordered behaviors and afflictions. Not to be outdone, NASA staged a press conference last year to declare on the most dubious of evidence that its grantees have discovered life on Mars. There's only one word to describe the money-driven publicity-mongering in contemporary U.S. science: disgraceful.

Leon J. Kamin
Professor of Psychology
Northeastern University
Boston, Mass.

I am glad that Allen retold the story of the bizarre eugenics movement and its tragic social consequences in the twenties and thirties as a warning to modern enthusi-

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asts. However, I was disturbed by some of the author's opinions and assumptions.

The article implies a blanket condemnation of all eugenics. This is clearly unacceptable. There is a big difference between a pregnant woman deciding to abort a fetus shown to carry some severe defect and a government forcing her to do so. The main threat of misapplied eugenics lies in its collusion with the legislative process. It is regrettable that Allen did not distinguish respectable eugenic concerns we all may have from state-controlled eugenics.

Also indefensible is Allen's position that "trying to sort out how much genes, as opposed to environment, shape human behavior is ultimately a scientifically meaningless undertaking." Difficult, yes; but meaningless? Think of the new understanding in human psychology, new methods of child rearing and education, and new pharmacological approaches that may result from genetic research.

As a geneticist, I should be very surprised if genetic influences on behavior, however complex, turned out to be trivial. Any honest research to clarify the nature/nurture interaction should be respected and discussed with an open mind.

GIUSEPPE BERTANI
Pasadena, Calif.

Allen's article struck me as a catalog of the author's personal biases used as red herrings to discredit eugenics. His preoccupation with the Nazi bogeyman indicates the simplistic emotional level of his presentation. Allen's background as a historian is obvious in the copious listings of bygone evils he uses as proof that eugenics cannot be used in good as well as evil ways. His approach is akin to denouncing surgery because knives have been used for evil purposes since ancient times. Instead of digging up obvious past evils only to academically denounce them, Allen should look forward in eugenics, as well as in all sciences, for constructive solutions to today's population problems.

WILLIAM N. MCNAIRN
Palos Verdes Estates, Calif.

Allen makes many good points about the weaknesses of early attempts to find genetic bases for intellectual traits, but his implicit view that there is no connection at all is as preposterous as the most naive genetic determinism.

The author writes that proposals to give Norplant to welfare mothers "run a striking parallel to the mood in late

Weimar and Nazi Germany." By implying that such proposals are wrong and possibly evil, he presumably thinks that we should continue the dysgenic policy of supporting as many children as an indigent woman chooses to have, even though a combination of genes and environment may repeat the cycle. The only alternative may be a birth-control requirement.

Nor can I accept Allen's apparent dismissal of the use of cost-benefit analyses in determining who can receive expensive medical treatments. We may find that it is not only burdensome but impossible to provide treatments whenever they are desired.

I wish Allen had clearly stated his opinions instead of hinting at them. His tactics and the attempt to eliminate the middle ground will promote rather than prevent the evils Allen fears.

JÖRGEN HARMSE
Austin, Tex.

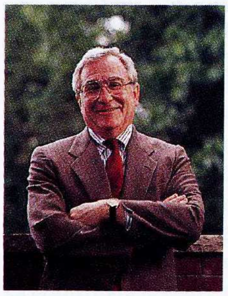
Wake up, Mr. Allen. Walk down the street to the local reproductive health center where eugenics is occurring daily, as donors are screened for physical and mental health, test scores, achievements, hair and eye color, and race.

NEIL A. CRONIN
Billerica, Mass.

A MATTER OF CONTEXT

As one who has realized over the years that both behavioral and pharmacological interventions influence cells of the immune system, I was delighted to read "Mindful Healing: An Interview with Herbert Benson" (*TR October 1996*). Benson is a pioneer in studying how stress and its reduction can interact with a wide variety of disease processes to either exacerbate or ameliorate their physical manifestations. His bold hypothesis that attitudes and mental states associated with religious belief can influence physiological processes associated with some diseases is a logical extension of his work in the field of psychoneuroimmunology, demonstrating that strong social support and a sense of control are powerful buffers against stress-induced diminution of immune responses.

All disease processes occur in the context of a living, behaving organism. Gerald Weissman's comment in the article that "bacteria, not stress" cause stomach ulcers reflects the narrowness of the unidirectional, reductionistic approach and the arrogance of its mechanistic thinking. The helicobacteria that "cause" ulcers most likely grow best in a milieu promoted by stress hormones and neurotransmitters. They probably could not even get started in their absence.



The medical profession's failure to embrace the context in which their patients' function has led to an either/or mentality that rejects attitude, will power, determination, stress, psychosocial influences, faith, and belief as unscientific. No wonder the American public is now seeking alternative approaches to healing.

DAVID L. FELTEN
Chair and Professor
Department of Neurobiology and Anatomy
University of Rochester Medical Center
Rochester, N.Y.

ENGINEERS IN THE CLASSROOM

I am one of the "Teachers at Heart" (*TR July 1996*) Samuel C. Florman writes about. After 25 years in engineering, I started a new career in 1982 when an instrumentation teacher at the local technical college had quit on the same day I walked in looking for work. Three days later, I stood holding a piece of chalk in front of 24 students.

In the Wisconsin school system, technical teachers are required to have two years of applicable work experience. On-the-job training for new teachers includes mentoring and seven courses required of education majors at state teachers' colleges. Certification must be renewed every five years.

I agree with Florman that a college degree in engineering is not necessarily overkill for teaching math and science to schoolchildren. Although I will probably never teach a class in advanced math or network synthesis, my background in those areas helps me explain the simpler concepts. An engineering degree also allows a teacher to read current technical literature and make appropriate changes to labs and classes to keep students up-to-date.

Engineers interested in switching to education should realize that the work is limiting and demanding. I spend most of my time teaching, correcting papers, and working on tests and lecture material. Although the academic year is shorter than the industry one, school obligations eat into "free" time.

Nevertheless, teaching has proved to be a very rewarding career change for me. I believe that one of the best ways engineers can finish out their careers is in education. Schools need teachers from various engineering fields to produce the best students.

KENNETH EXWORTHY
Marinette, Wis.

PERVERSE PROGRESS

I agree with Lester Thurow in "Building a Better Economy" (*TR May/June 1996*) that many Social Security recipients have not paid their way. For those who receive benefits but contributed little or nothing, Social Security is a welfare program and should be handled as such. What started out as a simple system with modest benefits for those who participated has rapidly ballooned into a massive program that has more welfare components than annuity aspects.

But Thurow's comment that "it doesn't make much difference whether you pay the (automobile) workers $40 an hour or $4 an hour" is dead wrong. When wages get too far out of line and unions exact whatever they want from a company, it usually ends in the failure of the company and a loss of jobs. In 1947, I joined General Motors, a great company trying to adjust to a peacetime economy and get back to making automobiles. However, unions, which seemed perversely intent on destroying the very industry that provided their members with jobs, posed a major problem. With the unions making annual demands, the smaller manufac-

turers simply closed. The larger companies tried to modernize their production methods and facilities but were blocked by the unions. The result was that Japan hired management and engineering people away from U.S. companies, put the ideas and methods into their plants, and entered the U.S. market.

ROBERT GRANVILLE WILSON
Houston, Tex.

GOOD FACTORIES, BUT FOR WHOSE GOOD?

While "When Bad Things Happen to Good Factories" (*TR July 1996*) appropriately considers how industry could better prepare for disruption, the setting of the article was breezy. It's been a long time since any thoughtful person assumed that what's good for General Motors is good for the country.

The GM strike the author refers to was a serious attempt to call attention to the potentially disastrous new tactic of outsourcing jobs to non-union companies, or of exporting them out of the country to take advantage of unspeakably low wages, horrifying working conditions, and poorly enforced, weak, or non-existent environmental laws. It is not only Lucy and Ethel who had to learn the hard way about the production line, and the tactics of capital and management. In 1991, former GM CEO Robert Stemple earned a $1 million salary to oversee 74,000 company layoffs. GM is not a "good factory," but a typical international corporation ready to sacrifice workers' lives, public safety, and the future of the environment in its quest for maximal profits.

MARC ESTRIN
Burlington, Vt.

YOU CAN/CAN'T TEACH AN OLD TYPIST . . .

I enjoyed reading "Dvorak Keyboards: The Typist's Long-Lost Friend" (*TR July 1996*) by David Tenenbaum. We at Sea Solar Power, Inc., where I am VP, discovered the Dvorak keyboard back in the early 1980s. We had one typist retrain on Dvorak and bought our first IBM Selectric typewriter with a Dvorak keyboard. When we bought our first minicomputer, a Wang 2200 system, we were also the first company in the country to order a Dvorak keyboard for this computer. Since that time, we have also used the control-panel options on the Macintosh and PC Windows environments to alternate between the QWERTY and Dvorak layouts.

My son, a high school senior, chose to learn Dvorak in typing class last year. He learned faster than anyone else in the class and completed the typing requirement in one semester far ahead of his peers even though his teacher insisted on also teaching him QWERTY.

With all the advances in ergonomic keyboards and the increase in carpal tunnel and tendinitis, I am amazed that big corporations do not recognize the ease and importance of Dvorak, which would substantially reduce wrist and hand problems far more than any ergonomically shaped QWERTY keyboard. As indicated by Tenenbaum, the time devoted to retraining on Dvorak is recovered very quickly in improved typing speed and fewer mistakes.

If we as businesspeople start retraining on our own, soon the schools will start teaching Dvorak. The improvements in health and worker output are well worth the effort.

JAMES H. ANDERSON, JR.
York, Pa.

In 1945, U.S. Navy Commander August Dvorak recommended that the Navy adopt his keyboard. As a test officer in an R&D group in the Army Quartermaster Corps, I helped conduct a feasibility study. Twenty civil-service typists in the Corps of Engineers in Chicago attended a three-week training session. *None* of the typists in this group ever recovered the speeds they had achieved before the retraining. The Dvorak keyboard is a great idea for people learning to type for the first time. Otherwise, do not attempt to break ingrained typing habits.

ROBERT J. PARDEN
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Santa Clara, Calif.

Continued on page 64

MIT Reporter

PUTTING A RUSH ON IDENTIFYING GENES

After 10 difficult years of work, researchers announced in 1993 that they had located the gene causing Huntington's disease. Since then, the pace at which other disease-causing genes have been found has greatly accelerated, so that genes are typically located in no more than two years. Now a new tool that can reduce the time needed for a critical step involved in gene identification, from perhaps as much as 10 months to a day, should allow gene discoveries to be made much faster still.

The tool is a map showing the approximate positions of thousands of genes—of still largely unidentified function—along the genome, the complete set of our 3 billion chemical "base pairs" of DNA. The map, which is being developed by an international consortium of 104 scientists, including researchers at the Whitehead/MIT Center for Genome Research (CGR), was made possible by a concerted previous effort that identified the chemical makeup of more than 450,000 short sections of DNA that lead to the manufacture of protein fragments. Researchers recognize that since genes direct protein production, the short sections—known as complementary DNAs, or cDNAs—are portions of genes and thus of potentially great value. But no widespread group of scientists has previously determined just what genes these DNA sections belong to.

An international consortium of 104 researchers has been developing a map showing the approximate position of thousands of genes along the human genome. Here Thomas J. Hudson checks robotic apparatus used to compare stretches of DNA, a step in creating the map.

The consortium workers began by taking copies of the cDNAs and, by comparing them for similarities, have created clusters, with each group representing an individual gene. From each cluster the researchers have then identified a representative cDNA and also looked for its presence in DNA sections whose locations on the genome are known from previous research. Where the cDNA shows up, as determined by a test that makes millions of copies of the representative material, suggests the proper map position for the cDNA and hence the probable location of that gene. To gain confidence in their placement decisions, the researchers have repeated this procedure. Because the task entails an enormous amount of repetitive work, Whitehead workers have relied on robots they earlier developed to compare stretches of DNA.

Rush to Publish

So far, the consortium members have positioned on the new "gene map" representative cDNAs corresponding to some 16,000 genes, of a total of perhaps 80,000 human genes, says Thomas J. Hudson, assistant director of CGR and recently also appointed assistant professor of medicine and human genetics at McGill University. These results, published October 25 in the journal *Science*, mean that the gene map today can help researchers rapidly locate genes of interest maybe one of every five times. But Hudson says he anticipates that the gene map could include perhaps 55,000 gene sites—corresponding to possibly two-thirds of all genes—within two years, with all information being added immediately to a new site on the World Wide Web. He notes that the consortium, which also includes researchers at the National Center for Biotechnology Information at the National Institutes of Health (NIH), Stanford and Oxford universities, the nonprofit institutes Généthon in France and the Sanger Centre in England, decided to publish the results after only one and a half years of work because the information could prove so valuable to genetic research.

A gene hunter can use the new map

PHOTO: SAM OGDEN

after first carefully studying families with a certain disease or trait and finding a large region of DNA inherited along with the condition. The map then immediately indicates to the researcher at least some of the genes lying in that region. In the past, finding candidate genes meant searching through amounts ranging from tens of thousands to perhaps a couple of million DNA base pairs—a step that could take months—for series of chemical units indicating various portions of genes. Removing any part of that process reduces the research period. The final step in identifying the correct gene remains the same: the scientist has to figure out which gene mutates to result in the condition of interest.

Consortium members have also included on the Web site some additional information on the mapped genes. By comparing the chemical makeup of those genes with that of other species' genes whose functions are already known, the researchers have been able to make educated guesses about the function of one-fifth of the genes listed on the site. Such details could make gene hunters' tasks easier still.

Francis S. Collins, the director of NIH's National Center for Human Genome Research, points out that the evolving gene map will not only speed up efforts to find single genes associated with certain diseases and traits but will be essential for locating the suites of genes associated with common conditions such as diabetes and obesity in which more than one gene plays a role. The use of "brute force" alone—the technique that had to be employed before the development of the gene map—to genetically identify the causes of such complex diseases would be "extremely difficult," he says, because many genes are involved. Without the new tool, he points out, researchers would be stuck with "a whale of a lot of DNA" to pick through.

—LAURA VAN DAM

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Business Lessons from Darwin

Natural selection may contain a key to helping companies develop faster, as well as more efficiently and singlemindedly. So concludes James Hines, a senior lecturer in MIT's Sloan School of Management, after spending two years testing analogies between the behavior of organizations and the evolution of biological species.

The parallels between organizations and organisms are striking, Hines maintains. As a prerequisite for evolution, for example, an entity has to be able to pass on a basic unit of information that initiates a stream of actions. In organisms this unit is the gene. "But corporations also have something that produces a stream of actions," Hines says, "and that's a policy." By policy he means any rule about how decisions are made—such as "We will raise prices when inventories are low, and lower prices when inventories are high." Every organization has a large genome of such policies—hundreds or thousands of them, both formal and informal—that govern their success in the marketplace.

In much the same way that genes are inherited through reproduction, policies are inherited through learning. While organizations foster learning in a number of ways, says Hines, "the most powerful mechanism is hierarchy": ideas and bits of ideas are handed down from superiors and combined with the concepts that underlings already carry in their heads. It is through this process that companies both perpetuate certain traits, such as a nurturing or a hard-hearted culture, and gradually develop and change.

The trouble with corporate evolution, however, is its haphazardness. In nature, reproduction offers organisms a simple and reliable way of passing on their genes, which are then evaluated with an unmistakable "fitness function," or criterion for success—namely, survival. In contrast, members of organizations are often unclear about what policies lead to success and about who among them carries the winning genes. In short, says Hines, "people don't know who to learn from."

But Hines is working on a solution. Taking a cue from a branch of computing known as genetic algorithms—wherein software "evolves" toward a goal through constant recombination and reevaluation—he has devised a series of steps that he hopes will allow organizations to seize control of their destiny. First the managers must decide on the fitness function for their company; they pick a goal or several goals, such as higher quality or higher profits or a more pleasant work environment. Then, says Hines, "to direct evolution, a company has to direct who learns from whom, in the same sense that plant and animal breeders have to determine who breeds with whom." A good way to do this is by promoting people strictly on the basis of achievements that directly advance the organization's goals. Thus, no matter where you are in the hierarchy, you know that learning from your boss will help you rise up the corporate ladder—and that whatever helps your ascent also helps the company.

The next step is recombination. This happens in organisms when the chromosomes from two parent cells "cross over," mixing and matching the traits of separate individuals. In an organization, the personnel would be periodically reshuffled; members of one division or design team would be traded with members of another, allowing the best policies to disseminate and to recombine with other ideas in beneficial ways. This practice may sound disruptive, but Hines is quick to suggest an upside: "While you lose the trust that might have built up between the five people on

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ILLUSTRATION: JON McINTOSH

a team, you also lose any animosity. And in time you'll build camaraderie among 50 people instead of just 5."

In theory a few rounds of promoting and reshuffling, promoting and reshuffling, should speed up the organizational learning process so that good policies emerge. Hines's computer simulations basically concur—but there is a catch: it turns out that promotions mean little without the possibility of demotion. In one simulation, for example, people were promoted according to how quickly their group managed to get a product out the door. Hines tried to be kind to the losers. "Because I'm a nice guy, I wanted everybody to get promoted; it's just that some people would get promoted more." To Hines's dismay, the simulation showed no change in time to market, even after many iterations: "Handing everybody a promotion does not give people enough information about who they should pay attention to," he says.

But, Hines discovered, if you demote people who perform worse than average and reward those who do better than average, "you get a dramatic reduction in time to market." It's probably no coincidence, he says, that McKinsey & Co., the management consulting firm with the highest revenue per employee, makes active use of demotions.

Does life have to be so cruel? "Believe me," says Hines, "I personally don't like this result. I don't like hierarchy and I don't like demoting people." But although he is still fleshing out his theories—preparing to test the effects of multiple policies and goals simultaneously—Hines is ready to give his reluctant endorsement to hierarchy as a driver of corporate evolution. Even though there are bad hierarchies that stifle creativity and communication, he says, "this form of organization may be uniquely powerful because so much is combined in each step up the ladder: money, power, freedom, your ability to accomplish things. So no matter what your motivation, you have incentives to move up the hierarchy, and to learn how to do that."

—DAVID BRITTAN

Trends

Detecting Stowaways

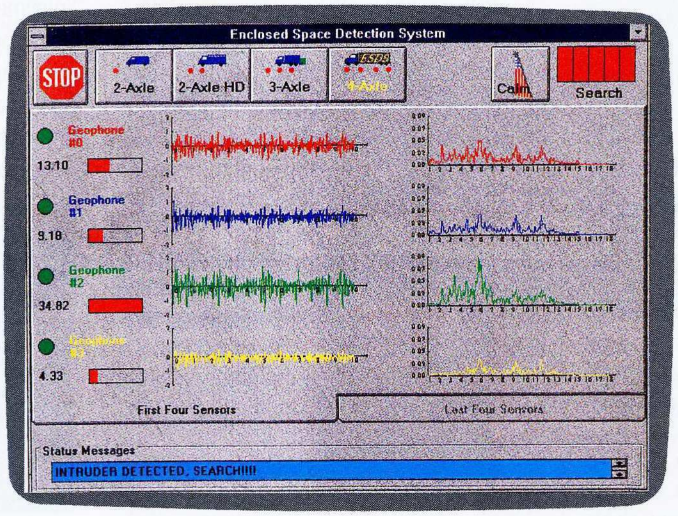
Had the ancient Greeks tried to use their Trojan horse to sneak into the Department of Energy's Y-12 facility in Oak Ridge, Tenn., they would almost certainly have given themselves away by a sound they couldn't control: the beating of their own hearts. Engineers at the national laboratory have developed a technology so sensitive it can pick up the sound of a heartbeat even when a person is well hidden inside a large vehicle.

The aim of the heartbeat detector is to catch terrorists attempting to gain entry to secured sites, prisoners trying to escape from jail, illegal immigrants crossing borders, even endangered animals being smuggled into the United States. So successful are early versions of the technology that it is being tested in maximum security prisons in California and in Tennessee.

The centerpiece of the technology is software that allows an ordinary portable computer to register the shock wave that the heart creates when it beats. The measurement of this wave, which is known medically as a ballistocardiac effect, is the mechanical equivalent of an electrocardiogram, which measures the intensity of the heart's electrical signals.

That the mechanical force of a heartbeat can be measured has been known since 1877, when Englishman J.W. Gordon correlated it to the jiggling readings he noticed while standing on a sensitive scale. What has not been clear until now is that the ballistocardiac effect can be measured as it induces slight vibrations in much larger objects such as cars and trucks.

In fact, tests show that a beating heart can perturb a tractor-trailer's walls, says Richard Pack, a design engineer at Oak Ridge. But the challenge was in trying to distinguish those vibrations from confounding factors such as wind blowing and doors opening and closing. Oak Ridge researchers conducted vibrational analysis of the ballistocardiac signal and discovered a pattern that featured several distinctive harmonic peaks and that varied from about 50 to 150 beats per



A novel prison-security system uses motion detectors to record vibrations from inside a truck (plots on left). It then displays a pattern showing the amplitude of various frequencies contained in the vibrations (plots on right). If a pattern matches that of a beating heart, the system signals the presence of an escapee.

minute. Given these characteristics, they devised a detection algorithm based on a common mathematical technique called wavelet analysis that is well known for its ability to distinguish impulse signals, even those spaced irregularly.

The detection algorithm in the Oak Ridge system receives data from either of two vibration-sensing techniques. One, undergoing testing at Centinela Maximum Security Prison near El Centro, Calif., places several motion detectors called geophones (which are traditionally used by geologists to hunt for seismic signatures that reveal underground pockets of minerals) on the roof, bumper, or other flat surface of a vehicle. The supersensitive devices contain a weight suspended in an electromagnetic field that when moved will generate an electrical signal. These signals are, in turn, relayed to a computer running the heartbeat-detection algorithm, which reveals a beating heart's vibrational characteristics and provides unmistakable evidence that someone is present inside a vehicle.

To test the efficacy of its technology, the Oak Ridge group has gone to great lengths to muffle the heart's characteristic sound. "We have rolled people in bubble wrap, in mattresses, in comforters, put them in tractor trailers and in garbage trucks three-quarters full of garbage, and the technology still works," says Leo Labaj, a technical operations manager at Oak Ridge.

The Tennessee researchers are also working on a microwave-based vibration-detection system that would eliminate the need for geophones, which must be placed directly on a vehicle. This technology would measure heartbeat-induced vibrations in a manner analogous to that used by a police radar gun tracking a speeding car. The detector would fire a microwave beam at the wall of a vehicle and calculate vibrations according to the subtle changes in the time, and therefore the distance, it takes for the beam to travel back. The Oak Ridge group plans to have a test microwave facility operating in a year.

In the meantime, Houston-based Geovox Security Systems is conducting further trials of the geophone-based system at Pelican Bay Maximum Security prison in California and Riverbend Maximum Security Institution in Tennessee. As part of the test, prison guards and other workers have been trying to smuggle themselves out of the compound. But so far, say Oak Ridge researchers, no one has evaded detection.

To install a geophone-based system at a prison entrance, from which pris-

PHOTO: LOCKHEED MARTIN ENERGY SYSTEMS

oners often try to escape (hidden, for example, in a truck), would cost somewhere between $55,000 and $65,000 dollars, says Geovox president, former Texas governor Mark White. But the price is reasonable, he says, because even an escape in which the prisoners are caught only a few miles from the prison can cost the state $100,000 in terms of manpower and equipment.

The Oak Ridge scientists do not know exactly how sensitive the heartbeat detector is at detecting fainter heartbeats. So far it has been able to reveal stowaway dogs and cats. But in the next round of tests, it will try to pick up a bird's heartbeat, an important milestone if the device is to be used to thwart smuggling of endangered parrots and other small animals.

The geophone-based detector is not without shortcomings. The main one is that it can be used only on a vehicle that is cushioned from the ground—for instance, by shock absorbers, springs, and rubber tires. If it is not, the earth itself serves as a kind of vibrational damper. That is, the vehicle and the earth virtually become one solid body. "Vibrations from heartbeats are strong enough to move a truck, but not strong enough to move the earth," explains Pack. This means that ships, which are essentially one with the water they rest in, and railroad cars, whose rigid steel wheels ride on steel tracks, will not vibrate strongly enough for heartbeats to be detected by the geophones.

To deal with this limitation, a container could be taken off a ship or a train and then put on a truck so a heartbeat inside it could be measured. The Oak Ridge group is hopeful that the microwave technology, which in initial testing appears more sensitive, might be able to pick up the faint heartbeat vibrations on boats and trains. If so, it may prove useful in detecting illegal immigrants attempting to enter ports or cross border checkpoints.—*STEPHEN STRAUSS*

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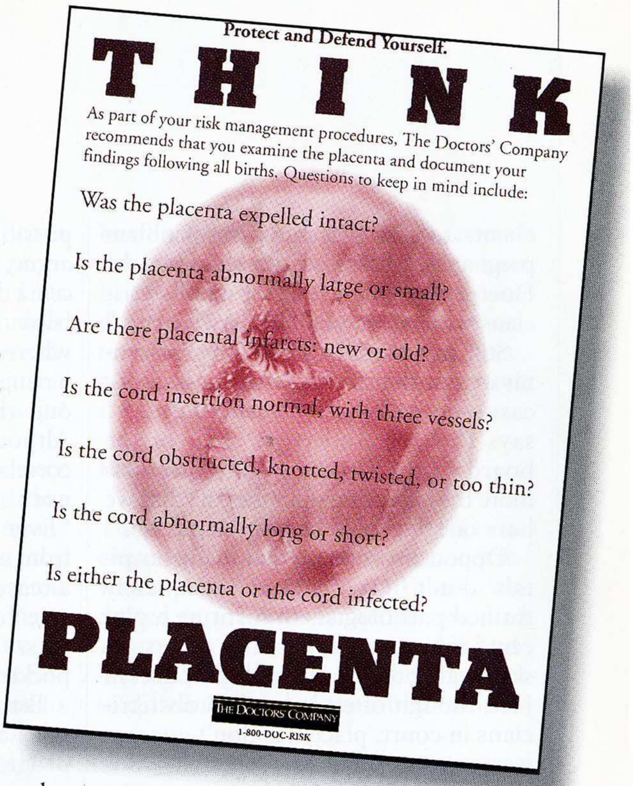
Placentas in the Courtroom

After giving birth recently to a baby with cerebral palsy, a woman in Tarrant County, Tex., felt she had just cause to sue her obstetrician and hospital, claiming that he had caused the brain damage and paralysis by failing to perform a prompt Cesarean section despite ominous fetal heart tracings. Indeed, doctors are often found guilty of negligence in such cases, and together with their hospitals are ordered to pay enormous amounts in damages. But this doctor was lucky. He had saved a valuable piece of exonerating evidence that most other obstetricians routinely toss out—the baby's placenta.

Laboratory tests on the placenta found a high count of nucleated red blood cells, suggesting that some type of infection had been present. Given these findings, the hospital's lawyers argued successfully that the infection had caused the cerebral palsy two to three days before the baby was born, making the timing of the C-section irrelevant. "The placenta came in very handy," says Richard Griffith, the lawyer who represented the doctor. "I would love to see placentas in all cases involving problem deliveries."

The placenta often holds the clues to a troubled pregnancy and can provide a strong defense in the event of malpractice suits, which occur frequently, says Daniel Dupre, claims supervisor at the Florida Physicians Insurance Co. In fact, malpractice cases, especially those in which parents seek compensation for a botched delivery resulting in a stillborn or brain-damaged baby, have become so common, he says, that "if you're a practicing obstetrician and you're not getting sued every two to three years, then you're not working hard enough." According to a survey conducted by the American College of Obstetricians and Gynecologists in 1992, nearly 80 percent of U.S. obstetricians have been sued for medical malpractice. For doctors and hospitals, losing one of these cases can cost potentially millions of dollars.



Malpractice insurers now urge obstetricians to routinely inspect placentas for anomalies that cause birth defects. Such evidence can exonerate doctors named in liability suits.

Placental abnormalities can offer critical evidence in such cases when the obstetrician is innocent of wrongdoing. For instance, a blood clot can be shown to have blocked the flow of oxygen to the baby's brain, causing mental retardation or cerebral palsy. And an abnormally small placenta can impede the transfer of oxygen from mother to fetus. Twins, in fact, are ten times more likely than single babies to get cerebral palsy because their placentas are more often tangled and small.

Because of its potential value, placenta testing has drawn a number of advocates. The College of American Pathologists has recently adopted guidelines recommending that hospitals store placentas from all births for at least three days and immediately test those that look abnormal or come from at-risk babies or mothers. Elsewhere, two of the largest malpractice insurance carriers, St. Paul Fire and Marine Insurance Co. and the Doctors Co., are also urging their

POSTER: THE DOCTORS CO.

clients to test placentas for problem pregnancies. Last year, for example, the Doctors Co. mailed all of its obstetricians posters that said "Think Placenta."

Still, most hospitals don't save placentas or test them. "It comes up in every case—do we have a placenta or not?" says Richard Anderson, chair of the board of the Doctors Co., "and it is more the exception than the rule that we have one. It should be just the reverse."

Opponents contend that many hospitals don't have enough adequately trained pathologists to institute a placenta testing program, while others are skeptical of the placenta's legal value. In fact, though often helpful to obstetricians in court, placentas don't guarantee a victory.

Plaintiffs will often challenge the results of a placenta test by arguing that the material was handled incorrectly and possibly contaminated. They may also argue, legitimately, that a damaged placenta doesn't always produce a damaged baby. They can even point to cases where a healthy baby was born despite having an abnormally small placenta or one that was infected or inflamed. Although abnormal placentas may be correlated with brain damage, tests cannot conclusively rule out other causes. "Even in the face of scientific evidence from a placenta, juries often decide that a reason needs to be found to compensate for a disabled child," Anderson says. "And they see hospitals as the deep pockets."

Perhaps the main reason more hospitals haven't instituted placenta testing programs is that, despite their many advocates, no one is willing to pay for them. Hospitals are wary of adding to the cost of a delivery. Henry Travers, a pathologist at McKennan Hospital and the Physicians Laboratory, Ltd. in Sioux Falls, S. Dak., and a governor of the College of American Pathologists, estimates that it would cost $50 to store a placenta for three days and $150 to test it, although he notes these figures vary widely depending on the hospital.

Medical Benefits

Moreover, despite the legal benefits, doctor and hospital insurance carriers like the Doctors Co. refuse to pick up part of the tab. "It's not appropriate for a placenta test to be subsidized by a medical liability insurer," Anderson says, "because that would undermine the test's credibility." Placenta tests should be prized for their medical benefits, not just their legal ones, he says. "One doesn't want to create the adversarial notion that we're doing a test in preparation for a potential lawsuit."

Travers agrees that placental testing can offer enormous potential benefits by alerting doctors to problems in the baby. For example, a pathologist may identify an infection in the placenta before the infant shows symptoms, allowing for earlier treatment. Testing the placenta can also help determine whether a stillbirth or birth defect is likely to recur in subsequent pregnancies.

Similarly, when babies are born missing hands or fingers, their condition is sometimes due to genetic factors, and is therefore likely to recur, but other times it is caused by amniotic bands that can develop in the placenta. The bands wrap around the fetus's finger or hand and cut off all circulation. Eventually, the limb falls off. Amniotic bands indicate the birth defect is not genetic and is not likely to happen in future pregnancies.

Understanding the reason for a child's brain damage or death can be a great comfort to parents. In turn, providing parents with a medical explanation may serve to prevent many lawsuits from being filed in the first place. According to Dupre of Florida Physicians Insurance Co., some parents who litigate are just looking for answers.—*LIZ LEMPERT*

Phantom Limbs and Rewired Brains

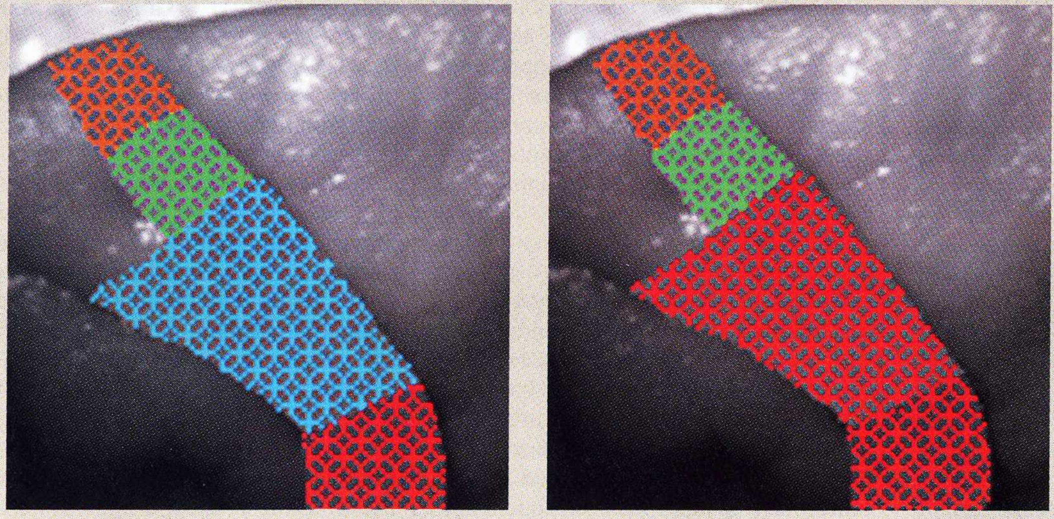
Phantom arms, legs, fingers and toes: seemingly the stuff of horror movies. Yet for nearly 70 percent of the 4 million amputees in the United States, vivid sensations in missing body parts—such as pressure, tingling, warmth, cold, and pain that can be both constant and excruciating—are all too real.

Phantom limbs have puzzled scientists for years. But recent studies have shed light on possible mechanisms underlying the phenomenon, including evidence that neurons in the brain that receive input from a limb may rewire themselves to seek input from other sources after the limb is amputated. These findings challenge the long-standing belief that the brain is immutable beyond a certain age and are leading researchers to develop new therapies for victims of phantom-limb pain and some spinal-cord injuries.

For years, psychologists attributed phantom-limb sensations to "wish fulfillment," a purely psychological condition. Then, in 1984, a team led by Michael Merzenich, a neuroscientist at the University of California at San Francisco, conducted experiments that began to explain phantom limbs as a true physiological response. Merzenich and his colleagues first amputated the middle fingers from a group of adult owl monkeys and later stimulated the digits on the hand of each monkey that were adjacent to the amputation stump.

Placing microelectrodes, which detect electrochemical changes in actively firing neurons, into various areas of the monkeys' brains, Merzenich found that the region of the cortex that originally fired in response to stimulation of the amputated finger was now triggered every time he touched the two adjacent fingers. The neurons had not responded to stimulation of these fingers before the amputation.

In 1991, Timothy Pons, a neuroscientist at the Laboratory of Neuropsychology at the National Institute of Mental Health, expanded on Merzenich's findings. Working with adult macaque monkeys, Pons and his colleagues "deafferentated," or cut, nerves that communicated sensory information between the cortex and the arm, forearm, hand, and rear of the head. The team then stimulated various body parts and found that the part of the cortex that had previously responded to the arm and back of the head now responded to stimulation of the face. Like ivy spreading over bare brick, Pons believes, surrounding neurons invaded the fallow cortical area corresponding to the deafferentated limbs, allowing it to respond to stimulation from other parts of the body.



Research on monkeys shows that brain neurons that normally receive input from the arm (shown at left in blue) realign themselves with neurons that receive stimuli from the face (shown at right in red) after nerves from the arm are severed. Such findings may lead to therapies for some spinal-cord injuries.

Human Trials

The following year, Vilayanur Ramachandran, a neuroscientist at the University of California at San Diego, conducted experiments on people who had an arm or a finger amputated. Blindfolding his patients, he applied pressure to different parts of their bodies. Corroborating Pons's results, Ramachandran discovered several subjects who reported that pressure applied to the face felt like it was coming from both the face and the phantom hand.

Ramachandran says that this finding made sense because the cortical territory once corresponding to the arm resided next to that corresponding to the face. And just as people standing next to barstools in a crowded bar are most likely to get those seats when people leave, neurons close to an area that no longer receives input have the best opportunity to move in.

PHOTOS: TIM P. PONS, ED ERGENZINGER

Ramachandran reasoned that the pain associated with phantom limbs might result when the neurons move into new areas but do a faulty job of rewiring themselves. Errors in cortical remapping, he says, such as "cross wiring" of touch and pain input could account for pain in, say, a phantom arm that occurs from a benign touch on the face.

The human studies also showed that cortical reorganization occurred more quickly than previously suspected. While Pons had studied primates who had been deafferentated for 11 years, Ramachandran found similar evidence in people whose limbs had been amputated only four weeks before the experiments.

The notion of neural regrowth and cortical reorganization represents a radical shift in the way scientists view the brain. "Historically, it was thought that there is a critical window of opportunity during development when the brain is wired," says Pons. Now, he says, it appears that the brain exhibits a surprising amount of plasticity throughout life.

Potential Therapies

Such plasticity could be the key to potential therapies not only for phantom-limb pain but also other afflictions of the central nervous system as well, including spinal-cord injuries in which inflammation or pressure is blocking neural pathways. In fact, over the past several months, Pons and his colleague David Good, director of the Bowman Gray School of Medicine Rehabilitation Center at Wake Forest University in North Carolina, have been observing patients with spinal cord injuries, comparing the degree of recovery to the amount of cortical reorganization as measured by MRI scans.

As expected, the researchers discovered that those who experienced the least amount of reorganization also had the most complete recovery. If the neurons do not reorganize, Pons explains, "then once things return to normal in the spinal cord, the cortex will remain unchanged and be able to function with the spinal cord the way it used to."

Pons and Good think that artificially preventing cortical reorganization could thus help patients recover from such spinal-cord injuries, though they caution the approach would be of no use in cases where the spinal cord is actually severed. One approach to blocking cortical reorganization that the researchers are investigating entails the use of DAP-V, a drug that inhibits the electrochemical activity of glutamate, a neurotransmitter in the brain.

Normally, glutamate enables communication between neurons as they pass electrochemical messages to one another from an external stimulus, such as a blow to the hand, all the way to the brain. Similarly, after a spinal-cord injury or amputation—when neurons suddenly stop receiving input signals from their neighbors—glutamate enables the abandoned neurons to connect with other neurons that will provide them with stimulation, thereby enhancing cortical reorganization.

Pons and Good say that binding up glutamate receptors with DAP-V will prevent neuron-to-neuron communication, so that the abandoned neurons, which are no longer communicating with their lifelong partners, won't be able to communicate with any potential new partners, either. Therefore, the researchers believe, neurons will stay tethered to their mates. And when the blockage to the spinal-cord dissipates, the original cortical connections and functions will remain intact.

Finally, because the cortical reorganization that takes place following amputation is so similar to the rewiring that occurs after spinal-cord injuries, Pons is hopeful that a pharmacological agent like DAP-V that prevents neural reorganization in the cortex might also help prevent phantom-limb pain in amputees. The researchers caution, however, that this research is in its infancy and has yet to address basic issues such as how the drug might be administered and whether it could be given for a brief period following amputation or whether it must be administered indefinitely.

—*URMILA RANADIVE*

In Praise of Superfly

When population geneticist Lisa Meffert began growing houseflies in her lab at the University of Houston back in 1982, she probably never expected that her experiments with the fast-breeding arthropods would throw into question some of the basic axioms of conservation biology. But her findings have done just that, and in the process have created a great deal of consternation among conservation biologists who adhere to traditional breeding techniques, particularly those trying to replenish dangerously low populations of endangered species.

Essentially, biologists have two options for bringing animals back from the brink of extinction. They can aim for the maximum number of offspring, or try to maximize genetic diversity: call it quantity versus quality. Usually biologists prefer quality, breeding the surviving adults as equally as possible, thus limiting the mating of prolific breeders—and thereby detrimental inbreeding—while allowing slow breeders to catch up and gain better representation among the progeny.

This strategy is based on the assumption that all the parents carry equally desirable genes and are equally deserving of representation. By preserving maximum genetic diversity in this way, breeders contend, the offspring will have the genes they need to cope with potential variations in future environments—say, changes in climate, prey behavior, or disease conditions. Overall, the goal is "to change the gene pool as little as possible" from that of the animals that were captured in the wild, says Jon Ballou, a conservation biologist who heads the captive-breeding program of golden lion tamarin monkeys at the National Zoo in Washington, D.C.

To ensure that the offspring best represent the entire population of adults, biologists such as Ballou typically use what's called a "pedigree" breeding program, which assigns breeding opportunities according to the relative rarity of one's offspring. The strategy ensures that all members of the "founder" generation have similar numbers of children, grandchildren, and great-grandchildren.

But could seeking quantity—the other breeding strategy—simultaneously improve quality as well? That's the implication of a series of experiments conducted by Meffert and Edwin Bryant, also a biology professor at the University of Houston, which have challenged the conventional wisdom of animal breeding. The researchers began thus by removing all but one or two pairs of randomly chosen males and females creating so-called "bottlenecks" in their housefly populations. To build up one population, they used a pedigree breeding strategy, but in another, they allowed the flies to breed at will.

Surprisingly, the pedigree technique favored by breeders of captive endangered species led to "nightmare population crashes" and lethargic flies that Meffert, with classic scientific drollery, says would be "selected against"—that is, eaten—in the wild. But when the scientists let nature take its course, leaving the males to compete for the opportunity to mate, the "superfly males," as Meffert calls them, bred with abandon, often with cousins and sisters (though not with mothers or daughters, since flies do

ILLUSTRATION: HENRIËTTE SCHERFT

not live long enough to mate with their offspring), and the offspring were much more vigorous.

Ballou of the National Zoo says that Meffert and Bryant's work is interesting, but he questions its relevance for captive breeding of animals for the wild. The fact that the offspring of the self-bred flies were more vigorous might be an artifact of an artificial breeding situation, he says, so what may seem like "letting nature takes its course" in captivity could be anything but. If certain parents produce more offspring, it could mean they are more fit to survive. But it could also mean that they are better suited to a captive environment and could be more vulnerable in the wild, he says. "We don't know enough about natural selection to impose our view of it."

Ballou points to another limitation on results from the Houston housefly experiments: they experienced much tighter bottlenecks than most endangered species undergo. Still, because the growing extinction crisis will put more and more animals ominously close to extinction, he concedes that it would be a good idea to test the Meffert-Bryant results with small vertebrates. Toward that end, Meffert is planning to conduct experiments with two endangered birds, the Micronesian kingfisher and Attwater's prairie chickens.

Another surprising Meffert-Bryant finding, which could bring breeders some solace, is that bottlenecks appear to be less damaging to genetic diversity than feared. These results come from tests involving so-called quantitative genetics. Unlike molecular biology, which can identify single genes, in quantitative genetics scientists use direct observation to examine traits that result from the interactions of many genes. Mating is one such trait, Meffert notes, because on the male side, for example, it requires genes that allow the fly to detect eligible females as well as to perform the mating dance and act.

A Good Word for Inbreeding?

Through such observations, Meffert and Bryant found a surprising rebound of genetic diversity—as measured by remarkable variation in mating behavior—in post-bottleneck flies. (The rapid but elaborate mating dance of the housefly is best appreciated in slow-motion video, Meffert says.) "It's an unexpected result," says Lukas Keller, an expert in

the genetics of song sparrows at University of Wisconsin-Madison. Right now, he adds, most experts believe that "a highly inbred population, or one based on a few parents, should be written off—that it's doomed to extinction" because of a lack of genetic diversity.

Meffert argues instead that a bottleneck can be an opportunity for getting rid of undesirable genes. It gives a chance to "purge bad genes from the population," she says, since only the fittest animals get to breed. In other words, she says, uttering another heresy, "inbreeding may be useful."

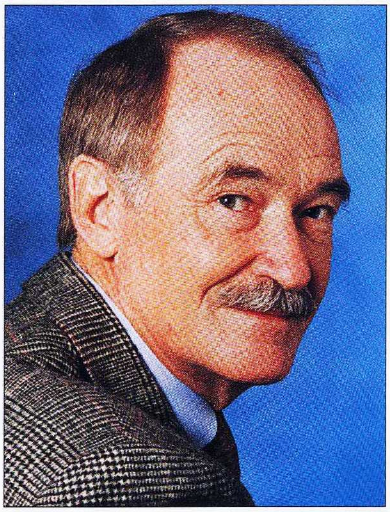
Meffert does admit, however, that bottlenecks could also purge positive genes, and thus would have to be used cautiously as a captive-breeding technique. In fact, she notes that some human populations have experienced bottlenecks, typically when small populations move to new islands or remote regions. In such cases, she observes, "Either they all died, or they [inadvertently] cleaned up their genetics and came up with a solution that worked for them."

So how best to ensure the survival of endangered species? Is there a middle ground that maximizes the genetic representation of today's individuals among tomorrow's generations but that still exploits the counterintuitive findings that animals may know better than animal breeders? Though more work needs to be done to verify her results with other species, Meffert says that combining her techniques with traditional methods could give biologists a new tool for replenishing severely depleted populations of endangered species. For example, she says, biologists could separate fast breeders into one group, essentially creating an artificial bottleneck, and let them reproduce with abandon, without fearing a loss of critical genetic diversity. Meanwhile, for added assurance, they could try to coax the reluctant breeders to reproduce as well. Afterward, assuming offspring from both groups survived, she says, the biologists could choose the animals they believed were most suitable for reintroduction into the wild.

—*David Tenenbaum*

Winning through Cooperation

AN INTERVIEW WITH WILLIAM SPENCER

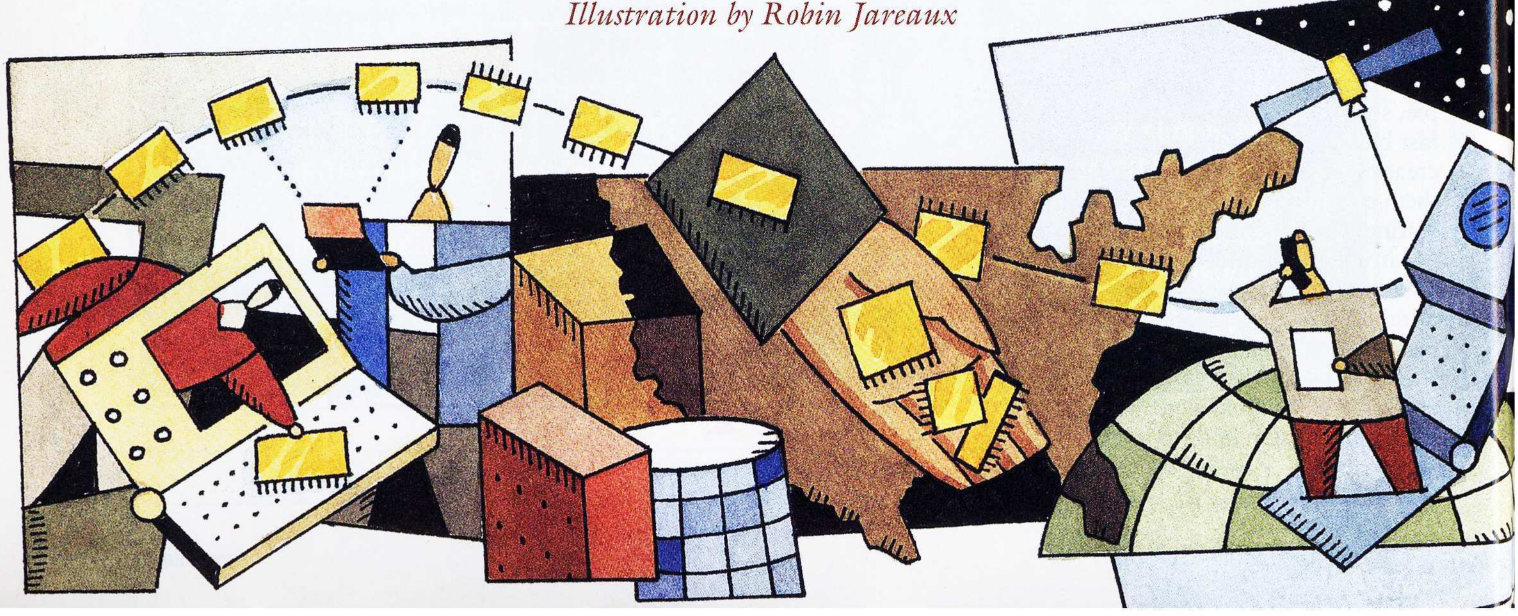


THE entrance to the headquarters of Sematech, the research consortium of chip manufacturers based in Austin, Tex., exudes a remotely military air. Vehicles entering the area must stop at a security gate, and once inside the main structure visitors must attach ID tags to their lapel while awaiting an escort to the building's inner sanctums. ❁ Such precautions reflect the seriousness of an enterprise touted as essential to the nation's security; it is chips, after all, that power the information economy. Incorporated in 1987 as a U.S. experiment in industrial policy, the venture was conceived to help stem semiconductor makers' precipitous loss of market share to the Japanese. The plan was to pool the industry's resources to refine the complex chip-manufacturing processes—an area of traditional American weakness. A clear bid to save a declining industry, the notion seemed radical partly because it arose amid the free-market rhetoric of the Reagan administration—and especially because it called for matching funds from the federal government. But the idea gained high ground when a report from the Department of Defense outlined an alarming future of relying on foreign sources for the brains of its high-tech weapons. President Reagan signed the bill authorizing $100 million in annual funding for Sematech that year.

Nearly a decade later, many have judged the experiment a success: the U.S. semiconductor industry now holds a slightly larger share than its Japanese rivals and, more importantly, is seen as a long-term world-class player. While even Sematech boosters do not claim the consortium deserves full credit for this turnaround, observers such as Michael Borrus, codirector of the University of California's Berkeley Roundtable on the International Economy, say it has clearly played a role by "convincing traditional rivals to cooperate." The industry's change in fortune recently prompted Sematech members to decline further federal funding.

William J. Spencer has led the organization since 1988, having arrived with the credentials essential to such a high-stakes position. Formerly head of research at Xerox's Palo Alto Research Center, one

Illustration by Robin Jareaux



The head of Sematech, the pioneering joint venture created to bolster the U.S. semiconductor industry, talks about the direction of U.S. research and development and the power of collaborative thinking.

of the nation's premier industrial R&D labs, he began his career at Bell Labs in 1959. Trained as a physicist, he says his career took a decisive turn when he developed a device for the first communications satellite in 1961. Inspired when the satellite actually functioned against great odds, he abandoned pure physics to pursue the practical challenges of engineering, working on microelectronics and systems development at Sandia National Laboratory before moving to Xerox.

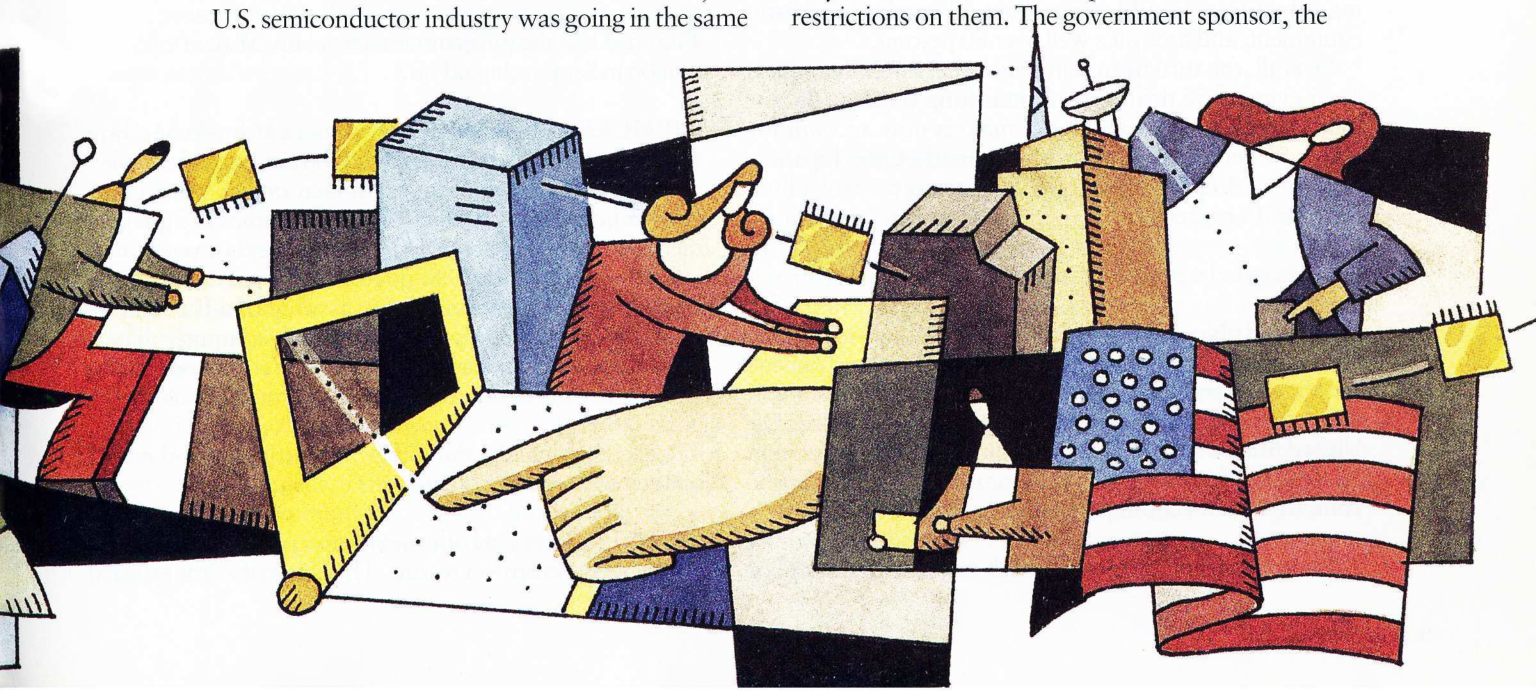
Professing, in typically modest fashion, that he's "made enough mistakes," Spencer has announced that he will relinquish responsibility for Sematech's daily operations as soon as a successor can be named (he will stay on as chairman of the board). In an interview with managing editor Sandra Hackman, he reflects on what Sematech has accomplished and where it has fallen short, and what lessons its experience holds for other cooperative ventures as well as for the overall U.S. research effort.

TR: How did this government-aided consortium manage to get off the ground? And how did the two vastly different cultures avoid insuperable conflicts?

SPENCER: Several factors were critical. First, the U.S. semiconductor industry was going in the same direction as the U.S. consumer electronics industry—into the tank. The Defense Science Board did a study indicating that by 1995 the United States would have less than 20 percent of the semiconductor market, and that eventually the domestic industry wouldn't exist. Most people would argue, as the Defense Science Board did, that you should not have to depend on foreign sources for something as crucial as semiconductors. In fact, every nation has said, if we're going to be a strong industrial player, we've got to have a position in this basic industry (which will probably grow from $200 billion now to $2 trillion in 15 years). Europe is spending a lot of money on maintaining a semiconductor industry, and so are other economic regions.

Second, industry leaders came together, realizing that even though they didn't know what ought to be done they had to do *something*. Fortunately, Charlie Sporck, then CEO of National Semiconductor, took a year's leave from his job to convince the country that launching Sematech was critical. The venture gained even more credibility when Bob Noyce, co-inventor of the integrated circuit, eventually agreed to run Sematech for its first two years.

Finally, the government not only matched industry's funding but did so in a very hands-off way: it sent the funds and put none of the usual restrictions on them. The government sponsor, the



Defense Advanced Projects Agency, did work with the consortium to establish annual goals and asked for a relatively brief report at the end of each year. But the agency did not micromanage—it essentially asked industry to manage a federal grant. The General Accounting Office did send representatives here for the first five years, but they left after seeing that the program was well run.

Proof of its success is that in 1995 semiconductor manufacturers told the government that we wanted to end federal support in 1996. Although we couldn't have made the same progress without it, we felt we could no longer justify that role given the industry's turnaround, and that we could continue progress on our own. And indeed the government has just concluded its financial investment in Sematech.

TR: Why did you decide to work intensively with the companies that produce chipmaking equipment, even though they are not formally members of the consortium?

SPENCER: The thinking was that if the United States is going to have a strong semiconductor industry, it had to have access to the very best equipment. It's the ever more complex machinery that keeps the semiconductor productivity engine turning. You certainly don't want to depend entirely on foreign sources for such critical equipment.

And the same thing that had happened to the U.S. semiconductor industry was happening in the equipment industry: the U.S. share had declined from nearly 100 percent in the 1970s to 40 percent in the late '80s. That convinced us to try to foster cooperation among the equipment firms, the materials industry, and the semiconductor companies to ensure that we get new manufacturing technology as cost-effectively as possible. We devoted some $900 million in R&D support—more than half of Sematech's funds—to that effort.

TR: And are U.S. manufacturers now buying more domestic equipment?

SPENCER: They are. Our goal was that semiconductor manufacturers would use at least 50 percent domestic equipment, and today it's well over 60 percent.

Overall, the turnaround in the equipment industry has been even more dramatic than among semiconductor manufacturers: U.S. equipment makers now account for about 55 percent of the worldwide market, the Japanese hold 35 or 40 percent, and the Europeans control a little less than 10 percent.

TR: Are sales largely domestic as well?

SPENCER: No. If you look at any U.S. high-tech company today, more than 50 percent of its sales occur outside the United States. My guess is that by 2050, those companies will be selling 90 percent of their product outside the United States. Much of the present foreign market is in Europe, but future growth will occur largely in the Pacific Rim, Africa, and South America.

TR: Do those companies establish new factories here or abroad in order to supply those expanding markets?

SPENCER: Both. Every manufacturer worldwide recognizes that if you're going to sell a chip-etching or lithography tool in another country, you're probably going to have to have a factory there, and this industry is no exception.

TR: If Sematech aids manufacturers who expand in other countries, how does that benefit the United States?

SPENCER: A large percentage of profits from those ventures return to the United States, and a lot of high-paying service jobs are created as a result, such as in R&D. That's why maintaining a strong manufacturing base is so important, and why every major economic region has a program designed to attain or retain one. If U.S. boards of directors are in the driver's seat, they decide where to build factories and do that R&D.

TR: So is the United States seeing a net gain in jobs in this industry?

SPENCER: Yes, but the situation is complicated. One of our young engineers came to see me the other day because he was very excited to report that he was taking a job in Malaysia—he and his wife think it's going to be a great lark to live there for the next four or five years. If that company were a Malaysian company rather than a U.S. company, my guess is that he wouldn't have gotten the job.

A company gets capital from wherever it's cheapest—maybe in Tokyo, maybe in London, maybe in New York. Similarly, a firm will get qualified people wherever it can to run a multibillion-dollar manufacturing facility. And since U.S. universities put out the most qualified graduates, more and more of those people are taking jobs worldwide. When I go to Taiwan or Korea today, it's almost like having a reunion with people I've worked with at Xerox and AT&T. In the future, instead of moving from Detroit to Dallas, more and more people will move from San Francisco to Kuala Lumpur.

TR: And has the government's total investment of $800 million in Sematech paid off?

SPENCER: The U.S. companies that have become stronger as a result have more than reimbursed the government in the form of taxes. In fact, one member company reported that it paid four or five times the government's share of Sematech's funding in taxes last year.

And of course the U.S. government, particularly the Department of Defense, is now assured of a U.S. source for key electronic components, and U.S. computer manufacturers can more easily decide when to introduce the next generation of microprocessors and memory chips.

TR: Do chip makers think they are getting a good return on their investment in Sematech?

SPENCER: Last year our members reported more than a 400 percent return—a record. The chipmaker that gained

the most from Sematech reported a sixfold return on its dues. Because these returns are so strong, member companies recently voted to increase their dues by 30 percent.

TR: How does a company measure its gain?

SPENCER: Sometimes it's easy. Suppose the consortium works to improve a piece of equipment, and that equipment reduces the cost of a chip manufacturer's $2 billion product flow by 1 percent. That represents a $20 million benefit right there. And the company avoids having to set up its own improvement procedures, which can also cost millions.

Sometimes the benefits to our members are less tangible but still invaluable. For example, the employees they send to Sematech for a two-year stint work on the most advanced equipment and carry that information back home. Those employees also make contacts that might otherwise take 10 or 20 years to establish. Finally, our members gain access to the results of Sematech's frequent meetings with European and Japanese consortia and share information from technical conferences.

TR: What does it cost a company to join?

SPENCER: We put a floor on joining: you couldn't get in for less than a million dollars. That caused a lot of complaint among smaller firms. But if you are a $200 million company and pay $1 million to Sematech, you get access to the same experiments and information that a larger company does by contributing $20 million.

TR: It sounds as though not too many small companies have joined Sematech.

SPENCER: Unfortunately not, although big companies with small semiconductor divisions—such as Hewlett-Packard, Digital Equipment Corp., and Rockwell—are members. That experience is typical: recently established U.S. efforts to develop advanced batteries and the next generation of automobiles, not to mention Japanese and European consortia, have seen a similar reluctance on the part of smaller companies, even though the benefits to them could be great.

TR: Might smaller firms fear divulging information about their processes, not to mention their problems?

SPENCER: That's entirely possible: we find that the employees companies send to work at Sematech are initially reluctant to talk about their problems and capabilities because they think they are unique. But after a short while they find that other companies are facing the same challenges and they can solve them and become more efficient and effective if they work together—it's an amazing revelation. In fact, if you ask our member firms about their major benefit from Sematech, they won't say the improved equipment or the advances in employee training but the better communication—both horizontally among member companies and vertically between member companies and suppliers.

TR: Does that kind of cooperation make Sematech a model for other industrial consortia?

SPENCER: We think it does—the U.S. car and battery consortiums are following our lead. And the imperiled textile industry, which is confronting many of the same problems we faced, recently created a consortium in collaboration with universities and national labs.

What's fascinating is that the Japanese have formed about four or five consortia in the past year that are almost identical to Sematech. And Europe has begun to move its electronics consortia in a similar direction.

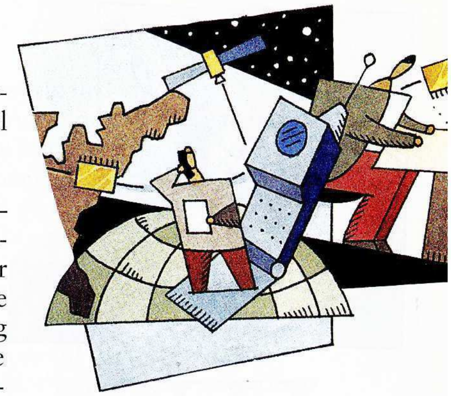
TR: How so?

SPENCER: Cooperative European R&D at first focused largely on developing products such as VCRs or memory chips, but those efforts didn't prove very successful. So the Europeans are now concentrating on infrastructure—developing new equipment and funding research on materials. They have some problems we don't: it's hard enough to get various U.S. companies to work together on any kind of project, but imagine trying to convince 15 nations in Europe to do so. I don't envy them.

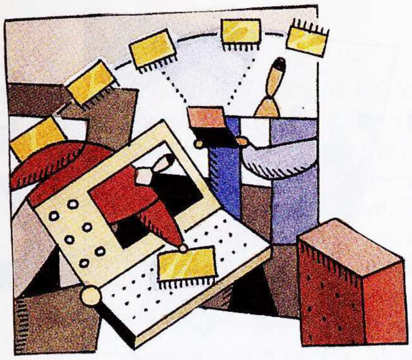
TR: Should foreign companies be allowed to join Sematech?

SPENCER: That's a major topic of discussion for the board right now: should we remain a national consortium? I think the issues we face today, whether related to economics, the environment, or health, are planetary issues. You can no longer do anything in one country that doesn't have an impact on the rest of the world. What's more, if Samsung and Hitachi build factories in the United States, the Environmental Protection Agency and the Occupational Safety and Health Agency are going to be investigating them, so companies might as well develop a common set of standards. And Sematech is a model for doing that because we've been able to find a way to cooperate yet compete very strongly in the market.

And chip makers from different countries are in fact



Our member companies quickly find that other firms are facing the same challenges and they can solve them if they work together.



We could make significant gains if we could apply our strength in managing complex technological systems to streamlining the manufacturing process.

starting to cooperate on setting environmental and health goals and complying with regulations. For example, we're working on ways to reduce the use of water and chlorofluorocarbons in the chip manufacturing process—there's no reason for each company or country to figure out how to do that individually.

We are also cooperating internationally on the move to larger wafers. One of the reasons this industry has been so productive is that the silicon wafers from which the chips are made get bigger: today we use 8-inch wafers but the industry wants to move to 12 inches. So we've started a program in which the wafer suppliers and the international semiconductor companies, including Korean, Taiwanese, and European firms, are all working together to set the standards for the equipment needed to process these larger wafers. We think we can save several billion dollars in what will probably be a $10–$15 billion conversion by having a single set of standards, and jointly measuring how the new equipment performs.

Setting Priorities for R&D

TR: What's your vision for manufacturing?

SPENCER: I think the United States could make a significant gain if we could apply our strengths in managing complex technological systems to streamlining the manufacturing process. By inventing the production line, Henry Ford set the tone for manufacturing throughout the industrial world for 75 years. And after the Second World War the Japanese improved the system by recognizing that if you bring parts to the factory "just in time" and you give a good deal more authority to the people working on the production line, you'll make higher-quality products at lower cost. So companies around the world adopted those practices.

But think about taking manufacturing to an entirely new level in which you integrate it with design and the customer. For example, if an engineer alters the specifications for a car fender, the factory immediately reprograms all the stamping tools on the production line and changes all the corresponding information available to every worker, shift manager, plant manager, and even customer. Doing that requires networking software—a field in which the United States leads: not a single network protocol or computer architecture in use anywhere in the world, except for maybe Nintendo, was developed anywhere else. And all programming languages are based on English—we own this business. Why can't we apply it to manufacturing? And what better place to start than semiconductors, because you can measure every step in the chip-making process using techniques already integral to production.

We should be able to set up recipes so that if the next batch of wafers or circuits coming through the factory requires a slightly different manufacturing approach, you just type in *b* instead of *a* and the system downloads the right specifications into the furnace, etcher, or other tool. The shift manager could instantly find out which tools are being used and which machine has got to have preventive maintenance tomorrow. The plant manager would know the status of every job in the plant. The customer could find out that custom microprocessors are at "final metal" and are going to "test" tomorrow.

TR: Has Sematech been aiming in that direction?

SPENCER: Aiming, yes. Hitting, no. When I came to Sematech, I thought, no sweat: I know a lot about systems and software, and we're going to apply that technology to semiconductor manufacturing. But although the consortium has spent a lot of money trying to do that, we have not yet made significant progress.

TR: Why do you think integrating design and manufacturing is so problematic?

SPENCER: It's very difficult to go into, say, a Motorola facility that cost $1.5 billion and has to yield $2 billion of revenue each year and say, if you shut your plant down for a week, I'm going to put in this software system that may raise your productivity 20 percent. The people who run the place are going to say, Not in my factory you're not. Not only is such an experiment risky but careers often depend on how well the factory does that quarter or year. What's more, the bosses are often physicists or chemists or materials scientists who don't know much about software systems except that the last time they tried to bring Windows 95 up on their home PC they had to call in some computer expert, and an entire factory is a thousand or maybe a million times as complicated as a home PC. Finally, computer scientists generally don't talk to other people and other people don't talk to computer scientists, so it's difficult to develop the right software.

TR: How can we solve those problems?

SPENCER: We have to get industry leaders more comfortable with software systems, and we've got to make the

software not only more reliable but also insertable in smaller pieces so operators can link various components rather than risking their entire manufacturing facility.

TR: How do we make sure that industry and government move in that direction?

SPENCER: I would like to see the engineering profession step up and play a major role in setting industrial goals—and indeed, in establishing R&D policy generally, the way physicists did at the end of World War II. The community could do that through the national academies. Those institutions aren't perfect, but they represent the common ground among universities, industry, and government.

To promote any kind of R&D venture effectively, engineers also need to communicate better with the public, which we are not always willing to do. In my view the arrogance of the scientific and engineering community cost it the superconducting supercollider (which was canceled in 1993). Scientists came in and said we're going to build this big machine and it's going to cost a mere $2 billion. Every year that figure went up. And when it got to $8 billion the research community asked President Bush to approach Japan and say, guess what, we've got this big hole dug in Texas, the experiments are set, and we're sorry your scientists didn't participate in deciding what they will be, but we need $2 billion.

We know where we want to go in basic science, we know what we need to do in semiconductors, we know what we need to do in software, we know what we need to do in biotechnology; we have clear road maps. But if citizens don't understand or believe that their lives will be enhanced, their kids smarter, and their air cleaner, then it's incumbent on the technology community to convince people that what they are doing will indeed pay off.

TR: Shouldn't social scientists, not to mention representatives of public-interest groups, also help set the goals for R&D?

SPENCER: I believe that getting social scientists to understand technology is harder than getting engineers to understand social issues, especially if engineers are broadly educated. But the notion of including non-engineers in setting R&D policy has great merit. I ran the national defense section of the Galvin Commission, which evaluated the future of the national labs in 1995, and at the last minute an individual from a public-interest organization was assigned to our group. He was a really interesting young man: he arrived with a chip on his shoulder—a feeling that we wouldn't listen to him—but he also brought a different perspective. He definitely changed the committee, and he underwent a change in his outlook toward us as well.

TR: Aside from working through the national academies, how can engineers become more involved in influencing the direction of R&D?

SPENCER: We've got to find a way to get more and stronger technical people into government—I think our community owes the rest of the world that kind of contribution. If we don't do everything we can to get more technologically sophisticated people into the administration and Congress, as well as onto congressional staffs, I think the nation's going to have a real problem, given the profound technological component of so many major issues. I would start by trying to pinpoint the best people in the country and getting them involved, as we did here at Sematech.

Japan does this wonderfully. Some of the top graduates from the best schools in Japan feel it's an honor to go into government. Yet very few U.S. engineers work on public policy in Washington after obtaining an advanced degree. The dilemma is that if I graduate from Berkeley with a PhD in electrical engineering, I'm tempted to take a job at my thesis adviser's new company because five years later I may be a multimillionaire. And in this country that's much more important than going to Washington to try to pass a significant piece of legislation, even though doing that would benefit a great many more people.

TR: Do the nation's R&D priorities need to change?

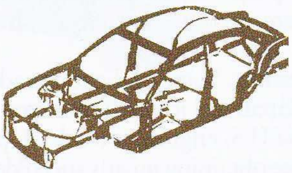
SPENCER: When the Cold War ended, the United States was spending most of its research funds in two areas of paranoia: fear of the Soviets, and fear of death. We were putting $15 billion a year into the National Institutes of Health and about a third of a trillion dollars into defense. We don't have to spend such sums on defense any longer; now we need to learn how to turn our fear of an enemy into a more positive drive to improve the quality of life.

In my younger years, I once proposed that if we're going to spend $15 billion a year on getting ourselves healthy, we ought to spend at least that much on having something to eat. Rather than hoping for civilian fallout from military spending, we've now got an opportunity to focus directly on economic strength, which today is as important as military strength. The National Institutes of Health provide a strong model for creating a science and technology institute that would focus on our national economic health. Alternatively, if you cut the nuclear weapons program and defense R&D by a factor of two, you could add that money to the National Science Foundation.

TR: Congress now often seems hostile to funding anything that's not basic research.

SPENCER: The people I've met in Washington are smart, hardworking, and dedicated. The problem is that we as a technical profession have not been able to get our story across as well as we should. We simply have to work harder at establishing a better relationship with members of the government at all levels.

The most important task is to create a mechanism for learning from past mistakes and successes and for applying the lessons to the next effort. That way we're always moving in the right direction, and Congress and the public can be confident that R&D funds are being well invested. ■



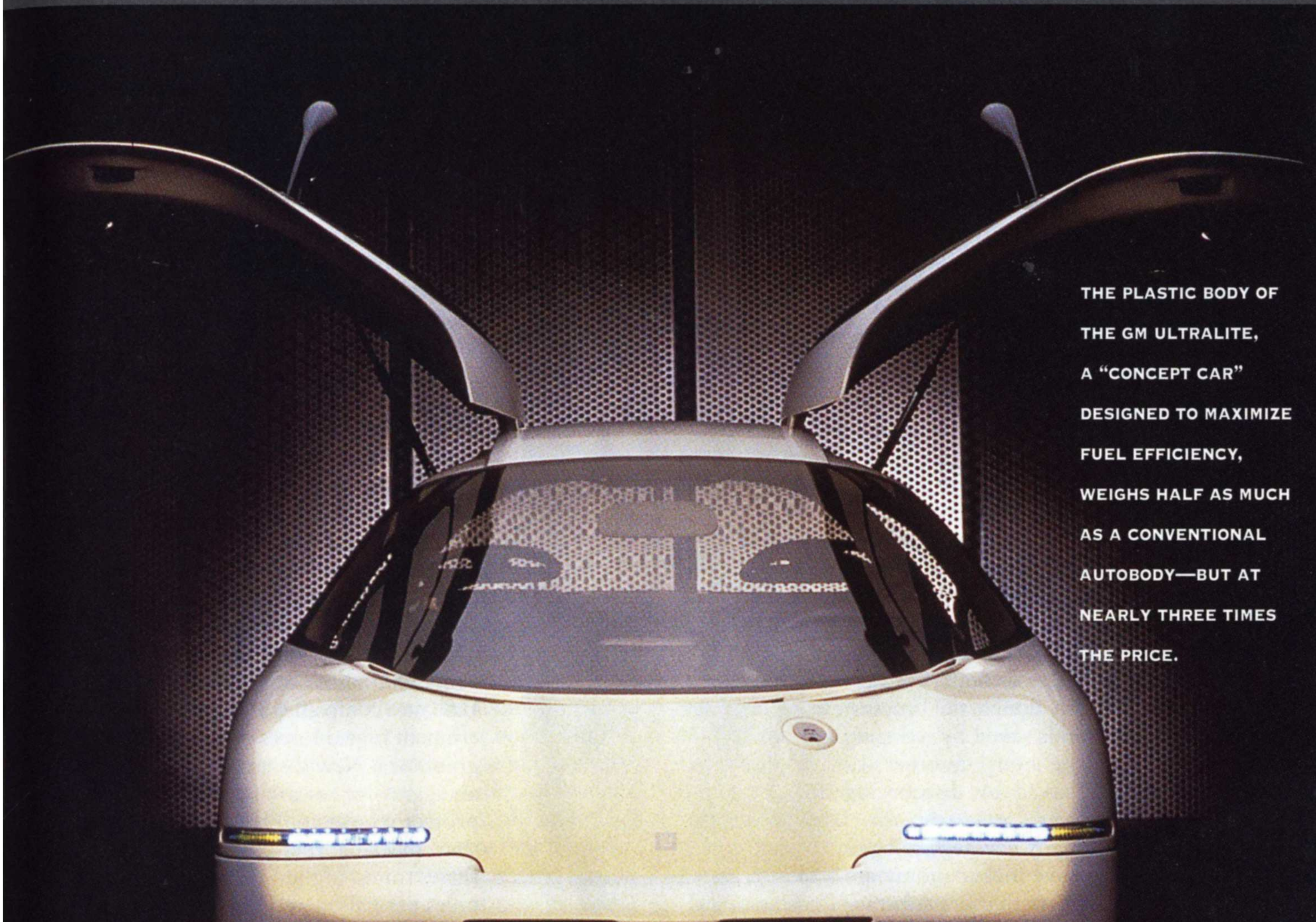
Sure, we could make the leap to a plastic "supercar"—but who could afford to buy it? The auto industry can get just as far, and achieve lower costs, by taking one step at a time.

THE automobile is the defining technological artifact of the twentieth century. Its familiarity, however, belies its complexity. It is no mean feat to design a car that is fast and powerful yet comfortable and safe—and still affordable. Factor in a few more constraints—durability, ease of repair, enough room for a few kids and the family dog, and an ample power supply for the electric windows, air-conditioning, CD player, and heated seats—and the challenge becomes clear. Precisely because the automobile has become an integral part of our lives, consumer expectations establish a set of formidable and often conflicting design objectives.

Over the last 25 years, automakers have faced growing pressure to incorporate environmental objectives into their designs as well. In particular, consumers and the federal government have pushed for improvements in fuel economy as a way to conserve oil and control pollution. The automobile industry has responded: the gas mileage of the average new car rose from 14.2 to 28.2 miles per gallon between 1974 and 1995.

A PRACTICAL ROAD TO

BY FRANK R. FIELD III AND JOEL P. CLARK



THE PLASTIC BODY OF THE GM ULTRALITE, A "CONCEPT CAR" DESIGNED TO MAXIMIZE FUEL EFFICIENCY, WEIGHS HALF AS MUCH AS A CONVENTIONAL AUTOBODY—BUT AT NEARLY THREE TIMES THE PRICE.

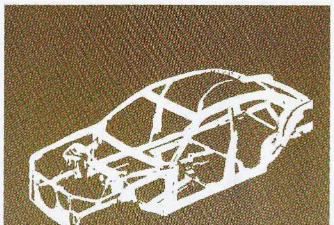
LIGHTWEIGHT CARS

Now public pressure to improve fuel economy is again rising, in part because of concern over the prospect of global climate change. (Automobiles account for about one-quarter of carbon dioxide emissions, a major contributor to the greenhouse effect.) The key to improving a vehicle's fuel economy is weight reduction: the smaller a vehicle is, the less power it requires to accelerate and the less energy to maintain a fixed speed. Traditionally, the automotive industry has reduced weight primarily by downsizing, a strategy that has succeeded in cutting the weight of a typical car from 3,500 pounds to 2,500 pounds over the past 20 years. Today, that strategy has reached its limits. Substantial improvements will be possible only through a new approach: making the automobile body out of lightweight materials instead of basic carbon steel.

Although the body accounts for only about one-third of the weight of an automobile, reducing the weight of the body is the sine qua non of the lightweight, fuel-efficient automobile. A car with a lighter body can use a lighter engine, a less massive suspension, and a less elaborate structure. These secondary weight savings can roughly double the benefits: for every 10 pounds saved by reducing the weight of the body, another 10 pounds can be saved by downsizing other parts of the car.

What's more, many new technologies designed to improve fuel economy are feasible only for cars that are substantially lighter than today's. Automobile engines, for instance, must balance the goals of efficiency (energy per distance traveled) and power (the force needed to accelerate the car). High-efficiency internal combustion engines, electric engines, or hybrid engines that combine the two are all far less powerful than conventional engines and will achieve a comparable level of performance only with a much lighter vehicle. Reducing the mass of the body is essential to creating a synergy between light weight and new engine technologies.

In 1993, a highly influential paper by energy analyst Amory Lovins of the Rocky Mountain Institute suggested that major automakers (or anyone else with the gumption) could use existing materials and technologies to produce an ultra-lightweight, highly fuel-efficient vehicle. The "supercar" he envisioned would incorporate lightweight plastics, computerized controls, and a hybrid powerplant—a power system that would combine a traditional heat engine and an electric motor, like a modern locomotive. It would weigh roughly 1,000 pounds and achieve well over 150 miles per gallon—yet it would retain the safety and convenience features of today's automobile.



Reducing the mass of auto bodies is essential to the use of new engine technologies that are highly efficient but less powerful.

Lovins pointed out, correctly, that the materials and technologies that would make a supercar possible are fundamentally incompatible with the design, manufacturing, and organizational processes around which the automobile industry is structured. He therefore argued that only a revolution in the industry would lead to a supercar; efforts to improve fuel economy and performance through the incremental adoption of new materials and technologies would cost too much and yield too little.

The supercar concept attracted a great deal of attention among environmentalists, auto industry leaders, and policymakers and even helped inspire an unusual alliance—though its goals fall somewhat short of Lovins's. In 1994, U.S. auto companies and the federal government joined forces to launch the Program for a New Generation of Vehicles, an aggressive research and development project whose goal is to produce a car that meets a fuel-economy standard three times higher than today's 27.5 miles per gallon and that offers the performance and convenience of a conventional car—for the same price. By combining the resources of the national laboratories and the major U.S. automakers, PNGV researchers hope to develop a prototype vehicle within 10 years and to mass produce and market it within 20.

The question is not whether an ultralightweight vehicle offering revolutionary improvements in fuel economy can be built. Automakers already know that it can. The question is whether such a car can be made affordable, and what kinds of changes in the automobile industry will be necessary to bring us closer to that goal. In particular, automakers and supercar proponents are debating the costs and benefits of two classes of materials that could serve as lightweight substitutes for steel in vehicle bodies: aluminum, which can be adopted with only incremental change in the industry's design and manufacturing processes; and plastics, which cannot.

Frank R. Field III is director of the Materials Systems Laboratory, and Joel P. Clark is a professor of materials science and engineering, at MIT.

Aluminum's Pluses and Minuses

A light metal 45 percent as dense as conventional steel, aluminum has been used as a major structural material in the aerospace industry for many years. Although it is expensive—aluminum sheet sells for about $1.50 per pound, compared with about 30 cents per pound for steel sheet—researchers in the automobile industry have begun to investigate the possibility of substituting aluminum for steel in vehicle bodies.

One of the main advantages of switching to aluminum, compared with other lightweight materials, is that it can be formed using many of the techniques already applied in making automobiles out of steel. Thus the industry could continue to use much of its existing equipment. And designing for aluminum is not drastically different from designing for steel—an important advantage in an industry where engineers are reluctant to experiment with relatively untried materials.

Of course, the fact that automobile bodies are not largely aluminum today suggests that the material also has disadvantages. Besides being more expensive than steel, aluminum is only about one-third as stiff—a crucial limitation in automobile body design. Stiffness can be increased somewhat by changing the geometry of the design (curved shapes are stiffer than flat ones), but this is problematic in an industry where shape and style are important sales concepts. An easier solution is to make flat aluminum body panels—fenders, hoods, and doors—thicker than steel panels to ensure that they perform equally well. This imposes higher material costs, however, and offsets the weight advantage to some extent.

Another problem is the high electrical conductivity of aluminum, which makes spot welding difficult. Spot welding is the standard method for assembling steel automobile bodies. The two parts being joined are clamped between two electrodes and electrical current is applied, thereby heating the two parts at the point of contact, leading to diffusion bonding. (The metal does not actually melt, since this would reduce the material's performance and lead to corrosion and part failure.)

Because aluminum conducts heat better than steel, it takes a lot more electricity and larger electrodes to make the metal hot enough to bond. And because the electrodes stay in contact with the aluminum longer while the current is being applied, aluminum atoms are more likely to diffuse into the electrode, shortening its useful life. Aluminum vehicles will probably therefore rely on alternative assembly techniques, including seam welding (in which a strip of molten metal is applied more or less like glue), adhesives, and mechanical fasteners.

Unibody versus Space Frame

The challenge facing the automobile industry is how to design an aluminum automobile so as to capture the advantages of the material and minimize the disadvantages. There are two competing possibilities: a unibody, short for "unitized body," the design used for steel automobiles; or a space-frame design, essentially a large truss structure covered with a thin skin.

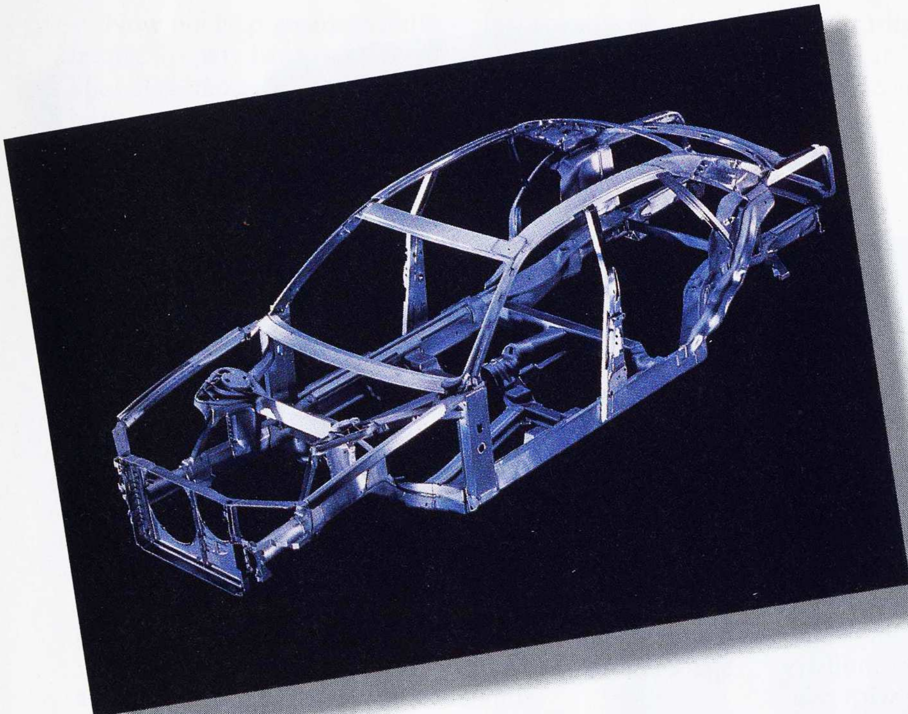
In a unibody, the vehicle's body panels are joined together to form a shell structure. This makes efficient use of the high stiffness of the body panels. Although aluminum is not as stiff as steel, if the panels are made thick enough and appropriate joining techniques are used, the unibody design will work well with this material.

AUTOMAKERS ARE BEGINNING TO EXPLORE THE FEASIBILITY OF ALL-ALUMINUM CARS SUCH AS FORD'S SYNTHESIS 2010, AN EXPERIMENTAL FAMILY-SIZE VEHICLE. MANY OF THE TECHNIQUES USED TO MANUFACTURE STEEL CARS ALSO WORK WITH ALUMINUM.

However, the unibody design poses two related problems. First, it is relatively difficult (and therefore expensive) to make complex surfaces, such as cutouts or elaborate curves, from relatively stiff metal body panels. If designers attempt to circumvent this problem by using materials that are easier to form, the second problem arises: because the unibody derives most of its structural performance from the way its parts are attached, those parts must be composed of materials that can easily be joined. Without an inexpensive way to fasten two dissimilar materials to one another, the unibody design essentially requires the automaker to manufacture cars using a single class of materials.

PHOTO: FORD MOTOR COMPANY

already used on a large scale to manufacture construction shapes such as window frames and pipes. Several designs for aluminum space-frame vehicles have been developed, each using differing combinations of extrusions, castings, and sheet metal. While the jury is still out, with the right combination of materials the space frame may someday challenge the unibody in mainstream automobile production.



IN A CONVENTIONAL CAR, STEEL BODY PANELS ARE WELDED TOGETHER TO FORM A "UNIBODY." TO CAPTURE THE ADVANTAGES OF ALUMINUM, DESIGNERS ARE EXPERIMENTING WITH A "SPACE FRAME" (ABOVE)—A TRUSS-LIKE SKELETON THAT DOES NOT RELY ON BODY PANELS FOR STRUCTURAL SUPPORT. ALUMINUM IS WELL ADAPTED TO SPACE-FRAME DESIGNS BECAUSE IT CAN BE FORMED INTO COMPLEX HOLLOW RAILS.

In response to these objections, designers are exploring the space frame. In this design, the vehicle structure is composed, in effect, of a lattice of metal rails, similar to a bridge truss. The vehicle does not rely on body panels for structural performance and in fact can be driven without any panels attached. This design does not work well for steel, in part because complex steel rails are not that much easier to make than complex steel body panels. Today the consensus among automakers is that the unibody is the most efficient way to make a mass-market vehicle out of steel.

However, the space frame is gaining renewed attention from designers working with alternative materials, especially aluminum. It is easier to make complex rails out of aluminum than steel because, unlike steel, aluminum can be extruded—formed into complex tubular shapes—in a process similar to pasta-making. These extruded, hollow rails can be far stiffer than solid bars of equivalent weight. Extrusion is easily adapted to mass production; it is

Is Aluminum Affordable?

An aluminum vehicle based on either design would bring us closer to the goal of building a lightweight car at a relatively moderate increase in cost. A typical steel unibody weighs just under 600 pounds, while an all-aluminum unibody weighs about 325 pounds and various aluminum space-frame designs would weigh between 285 and 385 pounds. Thus either design could cut the weight of the body nearly in half; a lighter engine, suspension, transmission, and so forth could double the number of pounds saved. (Of course, weight may be added in other areas to compensate for the deficiencies of the new design—for instance, a lightweight car cannot rely on its structural components to protect passengers in the event of a crash and so will need to employ additional systems, like airbags, which add some weight.)

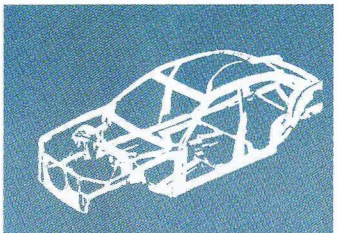
Just how much fuel savings are generated by lightweighting the body alone? Reducing the weight of the vehicle by 300 pounds can increase fuel economy by as much as 15 percent. This would increase the gas mileage of a typical mid-sized car, such as the Ford Taurus, from about 22 to about 25 miles per gallon, and reduce carbon dioxide (CO_2) emissions from about 410 grams of CO_2 per mile driven to about 355 grams per mile. Secondary weight savings would double the improvement in fuel economy and the reduction in emissions. More dramatic improvements in fuel economy would result in proportional decreases in CO_2 emissions, but these would require much more drastic measures than mere lightweighting: more efficient engine technologies, for instance, and probably less room and fewer conveniences than the American consumer typically expects.

A lightweight aluminum car based on either of these designs is likely to be somewhat more expensive than today's steel car when produced in large volumes, according to cost analyses by members of the Materials Systems Laboratory at MIT. At very low production volumes (less than 20,000 vehicles per year), aluminum space frames are actually cheaper than a steel unibody: the least expensive space-frame design would cost about $4,500, compared with $5,800 for a steel

PHOTO: AUDI

unibody and $7,200 for an aluminum unibody.

However, these production volumes are much too low for mass-market vehicles. Popular models such as the Ford Taurus are produced in volumes of 300,000 to 500,000. Even niche vehicles—luxury cars like the Lincoln Continental—have production runs between 40,000 and 80,000. To be considered affordable, a lightweight vehicle must be able to be manufactured inexpensively in large quantities.



The auto industry must figure out how to design an aluminum vehicle to capture the material's advantages while minimizing its costs.

At production volumes of about 100,000, the steel unibody is the cheapest design, at an estimated unit cost of $2,500. Aluminum space frames are a bit more expensive—the cheapest design costs about $2,800—while the aluminum unibody costs about $3,600. For more typical production runs of 300,000, the cost of the steel unibody declines to an estimated $1,400, and the aluminum unibody becomes cheaper than the aluminum space frame ($2,000 compared with $2,400).

The changing cost profiles for the three designs result from differences in their manufacturing processes. Metal stamping—the process by which both steel and aluminum unibodies are made—is better able to capture economies of scale than extrusion. As a result, the unit costs of both kinds of unibodies decline as they are produced in greater quantity; the cost differential between them is largely explained by the difference in the cost of the raw material.

The space frame follows a different pattern. Because the capital costs of extrusion are far lower than those of steel stamping, space frames are less expensive than unibodies at low production volumes. But extruded parts require finishing and heat treating, which are time consuming. Furthermore, the rate at which extruded parts can be formed is far slower than the rate at which stamped parts can be made. As a result, unit costs do not decline as dramatically when production volumes increase. Higher production volumes ultimately shift the economics in favor of the unibody.

Given that a vehicle with an aluminum body is going to cost $300 to $1,100 more than a vehicle with a steel body, will increases in fuel economy make up for the increased cost over the lifetime of the vehicle? The answer depends on a variety of factors: the total weight (and cost) of the vehicle, the efficiency of its engine, and the price of fuel. However, the increase in fuel economy attributable to the aluminum body alone would pay for itself only if the price of gasoline were to rise. If the price of gasoline remains between $1.20 and $1.50 per gallon, the money saved on gas would not be enough to make up for the higher cost: the life cycle cost of an aluminum unibody produced in volumes of 300,000 would remain about $300 more than that of a steel unibody. But if the price of gasoline rose to $2.30 per gallon, the owner of the aluminum-based car would break even over the vehicle's lifetime. It is reasonable to think that under these circumstances, consumers might be willing to pay the higher up-front cost of an aluminum-based car.

The Appeal of Plastics

Advocates of the revolutionary approach, however, stress the advantages of plastics as a more radical lightweight alternative to steel. Plastics are more than twice as light as aluminum and can be formed into a much wider variety of shapes. Moreover, the equipment used to manufacture plastics costs much less than the heavy stamping equipment required to make metal parts. These qualities have attracted automakers' interest since the 1960s.

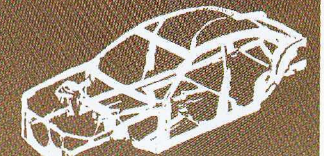
Today the industry has incorporated plastics in a variety of uses; they form the interior components of most cars, for example, as well as bumper covers and fenders. Manufacturers and designers have also used polymeric composites—plastics reinforced with either glass or carbon fibers—in the bodies of race cars and some commercially produced vehicles. In the 1980s, as automakers looked for new ways to reduce vehicle mass, many in the industry began to investigate the use of polymeric composites to substitute for steel in automobile bodies.

Like aluminum, composite materials have their disadvantages. For one thing, they are more expensive than other automotive materials. The plastic resin mixture costs between $1 and $10 per pound and glass fiber prices start around $1 per pound. Glass fiber polymeric composites are price competitive with aluminum or steel only when used in small quantities or in complex shapes that are prohibitively expensive to form from metal.

In addition, ordinary plastics are between one-thirtieth and one-sixtieth as stiff as steel, while reinforced plastics are about one-fifteenth as stiff as steel. The traditional uses of plastics in automobile interiors capture the advantages of light weight and ease of formation without requiring a high degree of stiffness. Unibodies, however, have to be stiff to perform effectively. Structural panels composed of reinforced plastics must therefore be much thicker than

their metal counterparts, offsetting the reduced weight and raising costs even further.

Carbon fiber composites have drawn the industry's interest as an alternative to glass fiber composites because they are stiffer. Panels composed of these materials can be made thinner—and thus lighter—than their glass-reinforced counterparts. However, carbon fiber composites are prohibitively expensive: carbon fiber prices start at $20 per pound and rise dramatically with increases in fiber strength and stiffness.



A critical problem is that the process of forming high-tech plastics is inherently slow, and thus unsuited to mass-production.

Polymer-based unibodies are also difficult to manufacture. Although bodies made of reinforced composites would require only one-third as many parts as conventional metal bodies, these parts would have to be made to fit together exactly—something that is beyond the state of assembly art today. Since plastic resin and carbon fibers contract at different rates as they cool, the parts are bound to warp and shrink slightly in ways that vary unpredictably from piece to piece. That's not unusual—steel changes shape as it cools, too—but materials like steel can be bent and twisted into shape. For instance, assembly-line workers use wooden mallets and two-by-fours to make sure steel car doors hang properly and seal when closed. Reinforced plastic components cannot be deformed in this fashion—plastic will break sooner than bend—so there is no easy way to compensate for slight imperfections in the way parts fit.

Finally, producing an affordable vehicle requires large-scale production, with volumes of at least 30,000 units per year and possibly an order of magnitude higher. While nonstructural plastic components can easily be manufactured on this scale, processing technologies for reinforced plastics are better suited to lot sizes of hundreds or thousands rather than hundreds of thousands. The cheapest way to shift to mass production of polymeric materials would be to speed up the process, making many more parts with the same equipment. But the processes involved in manufacturing and shaping reinforced polymer-based materials are not particularly amenable to this kind of straightforward scale-up.

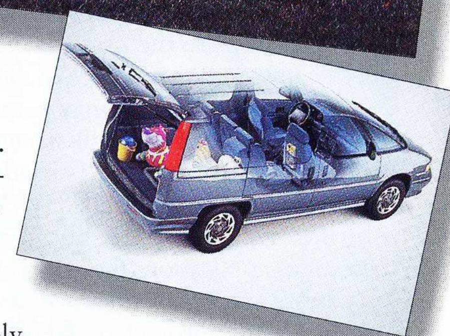
The critical problem is that processing these kinds of plastics is inherently slow. The parts are formed by preparing a mixture of ingredients and waiting for them to cool or react chemically. For parts the size of automobile body panels, this process can take a minute or more. By comparison, steel parts can be stamped in less than 10 seconds. It is hard to find ways to increase the rate of chemical reactions or the rate of heat transfer—if plastic cools too rapidly it becomes brittle, and if chemical reactions are sped up they become difficult to control.

To make a large number of plastic parts, then, automakers would need to buy multiple machines and set up parallel production lines—steps that would more than offset the capital advantage of plastic production and increase administrative overhead. While parallel production lines may sound feasible in theory, they are very difficult to coordinate in practice. As a result, automakers have tended to avoid processes that require more than two parallel production lines.

Ultralite=Ultracostly

How much weight could a plastic unibody save, and at what cost? The most radical polymer system is the Ultralite, a "concept car" based on carbon fiber composites that was developed by GM researchers given a mandate to obtain the highest possible gas mileage. The car, which was built by hand, incorporated a variety of weight- and fuel-saving technologies. Although the car was capable of getting more than 100 miles per gallon, it cannot be considered a prototype for a mass-market vehicle: it did not contain the space or safety features most consumers would consider essential and was never road- or crash-tested. Nevertheless, at 308 pounds, it represents the lightest auto body yet built of polymeric materials.

Although the Ultralite weighs about the same as an aluminum space frame, it would cost significantly more to produce in large volumes. At production volumes of 100,000, for instance, each Ultralite-style unibody would cost about $6,400. This estimate is based on the assumption that carbon fiber prices will remain at about $20 per pound. Proponents of polymeric materials have argued that the price of carbon fibers will decline as demand rises. But even if the price of carbon fibers fell to $5 per pound—a trend we do not foresee, since the production of carbon fibers is not necessarily amenable to economies of scale—the plastic unibody would still cost $3,500, compared with $2,500 for a steel unibody and $2,800 for an aluminum space frame at comparable production volumes. Moreover, at higher production volumes, the price of a steel or aluminum unibody will fall considerably, while the price of a polymer-intensive unibody will fall much less, mak-



ing it an even less economically sound choice.

It is unlikely that the increase in fuel economy attributable to the body alone would make up for the higher cost of a polymer-based body. At prices of $1.20 to $1.50 per gallon of gasoline, the Ultralite body would still cost some $4,500 more than either a steel or an aluminum unibody over its life cycle. In fact, carbon fiber-reinforced polymer-intensive bodies would still cost about $4,000 more than steel bodies even if gasoline prices rose to $4.00 per gallon, as is the case in Europe.

What Manufacturers Are Doing Now

Given the state of manufacturing art, the automobile industry has been taking an incremental approach to the use of new materials, gradually adopting new applications of aluminum, polymers, and advanced steels. For example, Ford is working closely with several aluminum companies on a project called Concept 2000 to produce 20 to 40 all-aluminum Taurus sedans, which the company is now testing and evaluating. The vehicle, which uses a unibody design, is only a few hundred pounds lighter than its steel counterpart, largely because the project engineers did not change the powertrain or suspension or redesign the vehicle to achieve other secondary weight savings. The project was intended only as a test of the manufacturability of an all-aluminum car, with the goal of identifying the changes in forming technology that would be needed to produce it. It is not yet clear whether Ford regards the experiment as successful.

Alcoa and Audi have collaborated on the Audi A8, a luxury sedan based on an aluminum space frame that is being produced at low volumes and marketed in Europe. Much of the weight savings gained by the use of aluminum are canceled out by accoutrements intended to boost the car's appeal in a high-end market. The vehicle does, however, demonstrate the viability of a design that utilizes aluminum extrusions and castings as well as the wrought sheet used in the panels.

The automobile industry is also attempting to develop production techniques to put plastics on mass-produced vehicles (notably GM's Saturn car lines), but even here the plastic components are not critical structural elements of the vehicle. All Saturns, for instance, use plastic body panels to cover a steel space frame. Because they have no structural role, the panels are made not of reinforced composites but of ordinary plastics, which can be produced in quantities of hundreds of thousands. The choice of material is governed less by weight considerations than by cosmetics: plastic panels give the vehicle its distinctive shape and resist dents and scratches. In fact, the weight saving achieved by the use of plastic panels is at least partly offset by the need to use more steel in structural components to maintain the expected level of performance.

Automakers have found that, with an aggressive effort, they can substitute polymers for steel in a handful of major nontraditional applications, such as roofs, hoods, floor pans, and engine cradles, but many are also discovering that the costs are too high and the weight savings unimpressive. GM has also experimented with glass fiber composites on the body panels of its APV vans for a number of years but recently concluded

MOST AUTO MANUFACTURERS HAVE CONCLUDED THAT PLASTICS ARE BEST ADAPTED TO NONSTRUCTURAL USES, SUCH AS IN CAR INTERIORS (CHEVY LUMINA, BOTTOM RIGHT) OR IN DOORS, FENDERS, AND TAILGATES (GM'S SATURN, TOP LEFT). THE GLASS-FIBER-REINFORCED PLASTIC BODY PANELS USED IN LUMINA VANS (TOP RIGHT) HAVE PROVEN TOO COSTLY TO MANUFACTURE: GM PLANS TO RETURN TO USING STEEL.

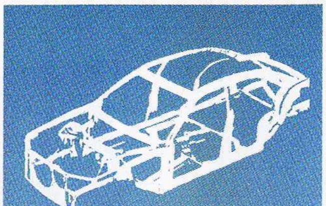
PHOTOS: GM CORP.

that the material is just too expensive. The company plans to return to using steel.

While they continue to experiment with glass fiber-reinforced polymers in niche-market vehicles—a well-established platform for innovation—automakers appear to have decided that these materials are not useful in applications with production volumes over 80,000, because at these volumes the benefits do not justify the costs. Moreover, it appears that the industry is already using plastics in most of the applications that are best suited to the material's strengths. Further substitutions of plastics for steel will be much harder to accomplish, because these are the uses that capitalize specifically on the properties of metals.

Another material that may play a role in incremental change is high-strength steel. The thickness of steel parts used in automobiles is usually determined by the degree of stiffness they require, but in about 20 percent of applications the important property is strength. For instance, a beam in every car door protects passengers in the event of a crash. New high-strength steel alloys are two to three times as strong as conventional carbon steel, so a beam made of the new material could weigh one-half to one-third as much as the beam used in car doors today. A number of steel companies based in different countries have hired Porsche Engineering Services to come up with a body design incorporating all the potential applications of lightweight steel. They estimate that the body could weigh 10 to 20 percent less than a conventional steel unibody, at a cost up to 15 percent higher.

The Program for a New Generation of Vehicles, meanwhile, is investigating the potential uses of advanced steels, plastics, and aluminum, as well as such exotic—and expensive—substances as magnesium and titanium. At this early stage, researchers are trying to identify the technologies that could make up the platform for an affordable advanced vehicle. They appear to be focusing their efforts on the concept of a hybrid diesel-electric engine, for instance, and on aluminum as the dominant material for structural applications (although the vehicle will undoubtedly incorporate a variety of advanced materials for other uses.) Whether or not the program ultimately succeeds in developing a vehicle that is affordable—and there are rumblings that insiders believe it won't—the effort will give the auto industry valuable experience with new materials and technologies.



Whatever strategy the industry adopts, a vehicle made of lightweight materials is clearly going to cost more than today's conventional car.

Concentrating on What We Can Do

Whatever strategy the industry adopts, a vehicle made of lightweight materials is clearly going to cost more than today's conventional car. The fuel economy of these vehicles is also going to depend upon a lot more than the shift to lightweight materials; significant gains will require changes in consumers' expectations. Given our assumptions about how roomy a car should be, how swiftly it should accelerate, how fast it should go, and how comfortable it should be to ride in, it is difficult to make a car much lighter than, say, the all-aluminum Taurus that will still be a vehicle most of today's consumers want to buy.

Nevertheless, the specter of the supercar haunts the debate over carbon-dioxide-induced global warming and feeds public pressure for government to mandate more radical reforms. If we can make a better tennis racket out of Kevlar, the argument goes, why can't we make a better automobile out of the same kind of material? One answer is: although consumers may be willing to pay three times as much for their advanced composite tennis rackets, they are unlikely to be willing (or able) to pay quite the same price premium for an advanced composite car.

A supercar like that envisioned by the Program for a New Generation of Vehicles—one that achieves 80 miles per gallon, maintains the same level of convenience, and costs the same as today's car—is beyond our capabilities today and for the near future. Any two of these three objectives can be achieved today, but putting all three together will require major technological breakthroughs. It is thus impractical for the industry to jettison today's automobile designs and technology to pursue this technological chimera.

Because we cannot mass-produce an affordable, ultra-lightweight polymer-based vehicle body, we should concentrate instead on what we can do. For instance, we can make an aluminum body that performs as well as the steel alternative but costs only marginally more. The incremental application of the broad spectrum of advanced materials technologies available today can yield real benefits in efficiency, utility, and performance without incurring insupportable costs. Although relatively unexciting and unglamorous, incremental strategies for vehicle weight reduction are the only credible approach for beginning the transition to an economical, fuel-efficient vehicle.■

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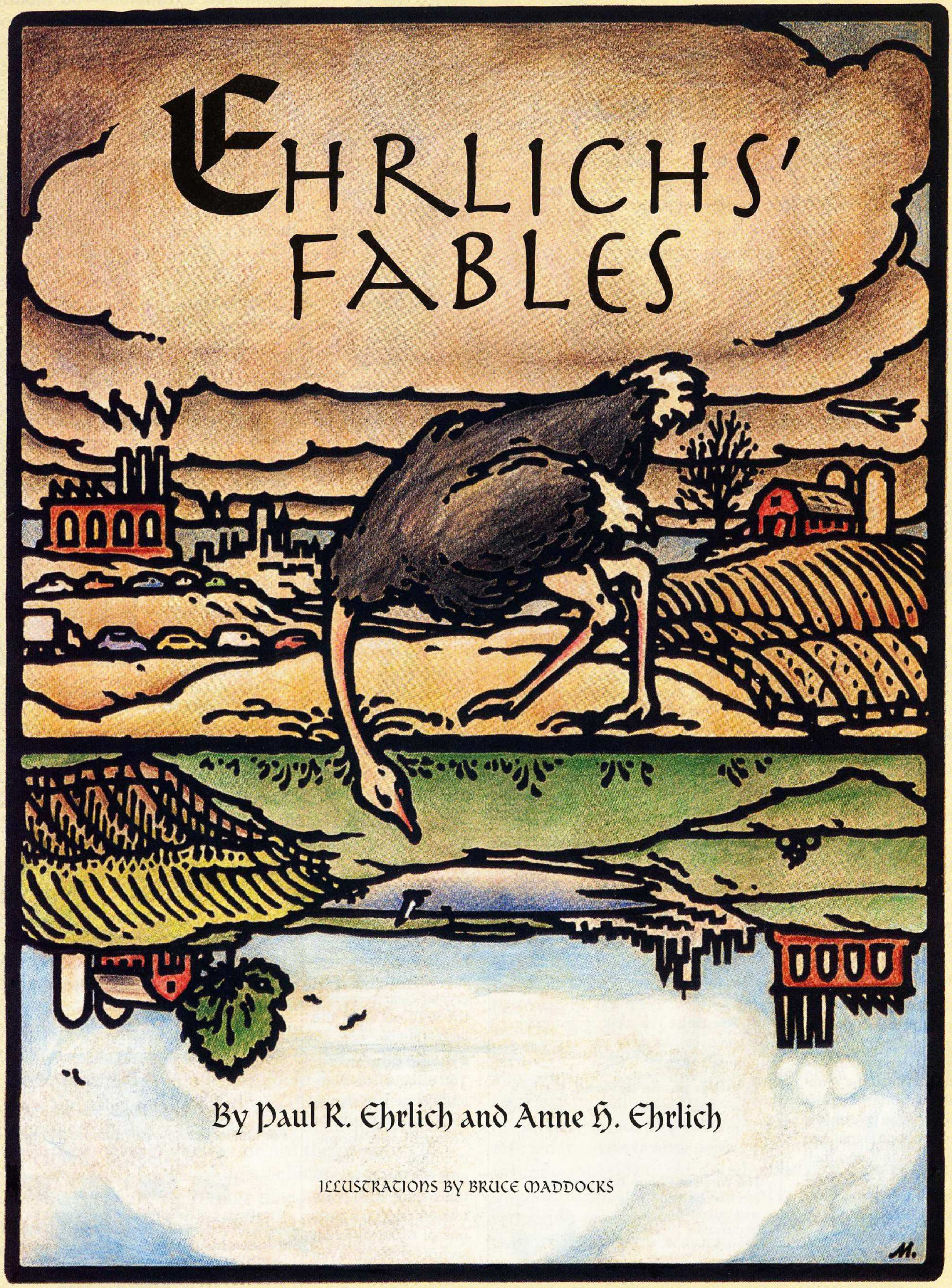

EHRLICHS' FABLES
By Paul R. Ehrlich and Anne H. Ehrlich
ILLUSTRATIONS BY BRUCE MADDOCKS
M.

THE PUBLIC HAS BEEN HEARING SOME FANTASTIC TALES LATELY THAT ALL IS WELL WITH THE ENVIRONMENT AND THAT GOVERNMENT REGULATIONS SERVE ONLY TO STIFLE ECONOMIC GROWTH. TWO PROMINENT ENVIRONMENTAL SCIENTISTS ARGUE THAT PROMOTERS OF THIS "DON'T-WORRY, BE-HAPPY" POINT OF VIEW HAVE THEIR HEADS IN THE SAND.

When polled, 65 percent of U.S. citizens say they are willing to pay good money for better environmental protection, but at the same time most do not believe that environmental deterioration is a crucial issue in their own lives. This seeming contradiction may stem from the fact that it is difficult to recognize subtle and gradual environmental change. But it may also stem from another fact: that various sources, including conservative think tanks such as the Cato Institute and the Heritage Foundation, have been disseminating erroneous information regarding the true state of the environment. Adam Myerson, editor of the Heritage Foundation's *Policy Review,* pretty much summed up this viewpoint in the journal when he maintained that "leading scientists have done major work disputing the current henny-pennyism about global warming, acid rain, and other purported environmental catastrophes."

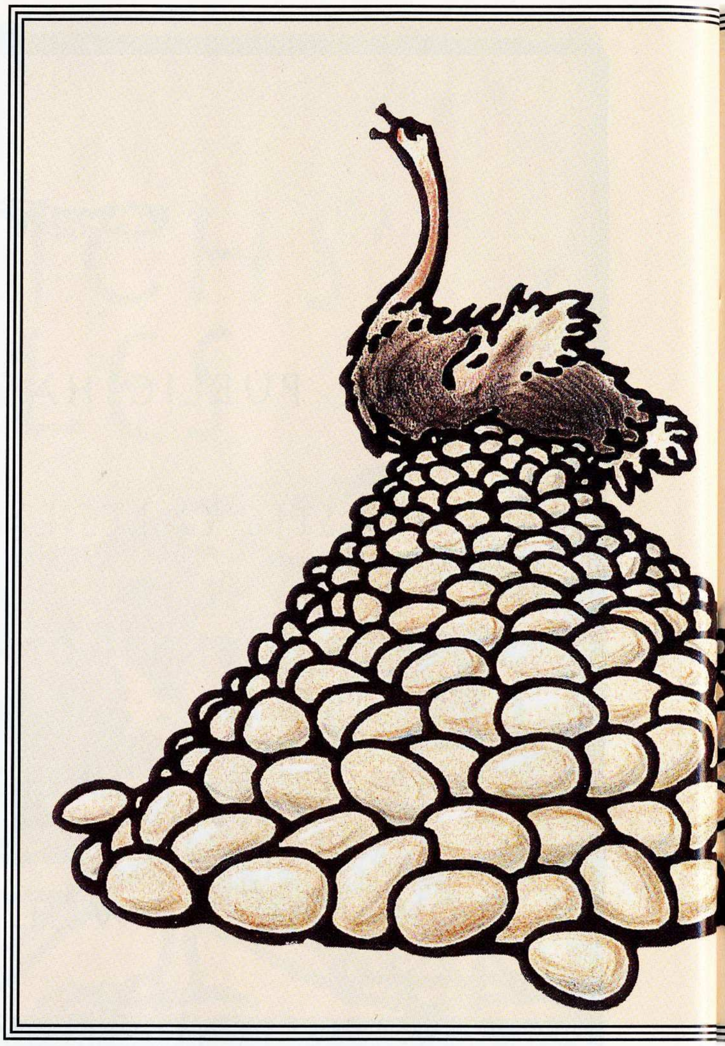
A flood of recent books and articles has also advanced the notion that all is well with the environment after giving undue prominence to the opinions of one or a handful of contrarian scientists in the name of "sound science" and "balance." With strong and appealing messages, these authors have successfully sowed the seeds of doubt among policymakers and the public about the reality and importance of phenomena such as overpopulation, global climate change, ozone depletion, and loss of biodiversity.

If U.S. citizens were convinced that some changes could enhance their quality of life and that of their children, most would gladly oblige. But when the necessity of such changes is questioned, especially in the name of science and reason, it's not surprising that most people are hesitant to embark on the necessary course to tackle environmental problems.

What follows is a sampling of the myths, or fables, that the promoters of "sound science" and "balance" are promulgating about issues relating to population and food, the atmosphere and climate, toxic substances, and economics and the environment. By looking at them through the lens of the present scientific consensus, we aim to reveal the gross errors on which they are founded. Thus we may return to higher ground and engage in a crucial dialogue about how to sustain the environment.

Fables about Population and Food

There is no overpopulation today because the earth has plenty of room for more people.



In fact, humanity has already overshot earth's carrying capacity by a simple measure: no nation is supporting its present population on a sustainable flow of renewable resources. Rich agricultural soils are being eroded in many areas at rates of inches per decade, though such soils are normally formed at rates of inches per millennium. Accumulations of "fossil" fresh water, stored underground over thousands of years during glacial periods, are being mined as if they were metals—and often for low-value uses such as irrigating forage crops like alfalfa, for grazing animals. Water from those aquifers, which are recharged at rates measured in inches per year, is being pumped out in feet per year. And species and populations of microorganisms, plants, and other animals are being exterminated at a rate unprecedented in 65 million years—on the order of 10,000 times faster than they can be replaced by the evolution of new ones.

We needn't worry about population growth in the United States, because it's not nearly as densely populated as other countries.

The idea that the number of people per square mile is a key determinant of population pressure is as widespread and

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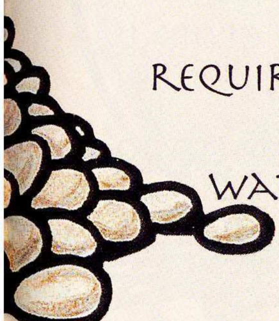
THE QUESTION IS NOT HOW MANY PEOPLE CAN FIT INTO A GIVEN SPACE BUT WHETHER THE EARTH CAN SUPPLY THE POPULATION'S REQUIREMENTS FOR FOOD, WATER, AND OTHER RESOURCES.



persistent as it is wrong. In *Apocalypse Not*, published by the Cato Institute, economist Ben Bolch and chemist Harold Lyons point out that if the 1990 world population were placed in Texas, less than half of 1 percent of earth's land surface, "each person would have an area equal to the floor space of a typical U.S. home." They also say: "Anyone who has looked out an airplane window while traveling across the country knows how empty the United States really is."

But the key issue in judging overpopulation is not how many people can fit into any given space but whether the earth can supply the population's long-term requirements for food, water, and other resources. Most of the "empty" land in the United States either grows the food essential to the well-being of Americans and much of the world (as in Iowa), supplies us with forestry products (as in northern Maine), or, lacking water, good soil, and a suitable climate, cannot contribute directly to the support of civilization (as in much of Nevada). The point is that densely populated countries such as the Netherlands, Bermuda, and Monaco and cities such as Singapore, São Paulo, Mexico City, Tokyo, and New York *can* be crowded with people only because the rest of the world is not.

We should have a bigger population for no other reason than that "people like to be alive."

One can respond to such statements by asking, "Would people like to be alive if they had to live like chickens in factory farms?" But such retorts are unnecessary. The best way to maximize the number of Americans (or Chinese or Nigerians) who live wouldn't be to cram as many of them as possible into these countries in the next few decades until they self-destruct. Rather, it is to have permanently sustainable populations in those nations for tens of thousands, perhaps millions, of years.

We need a larger population so we will have more geniuses to solve our environmental problems.

Having additional people to work on problems does not necessarily lead to solutions. Consider what happened to the people of Easter Island after this lush, 64-square-mile subtropical Pacific island, some 2,000 miles west of Chile, was colonized by Polynesians some 1,500 years ago. Even as the population soared to around 20,000, all those minds couldn't solve the tiny island's resource problems. The large forest of towering palm trees that graced the land was harvested more rapidly than it regenerated. Once they were gone, there was no way to build canoes for porpoise hunting, and without the forest to absorb and meter out rainfall, streams and springs dried up, unprotected soil eroded away, crop yields dropped, and famine struck the once-rich island. Unlike most premodern peoples, the islanders apparently didn't limit their fertility. Instead, as food supplies became short they switched to cannibalism, which turned out to be an effective—if not very attractive—method of population control. A common curse became, "The flesh of your mother sticks between my teeth."

Can't today's population, with its knowledge of the histories of past civilizations and billions of working minds, help us avoid the fate of the Easter Islanders, and the Henderson Islanders (who completely died out on one of the Pitcairn islands in the South Pacific), the classic Mayans, the Anasazi (Native Americans who built the vast pueblos of Chacon Canyon), and others who destroyed the environmental supports of their societies? We wish the answer were yes. Yet the billions of human minds we have today are not stopping society from destroying its resources even faster than earlier civilizations destroyed theirs.

But that aside, perhaps the larger point is that environmental rather than genetic differences determine what proportion of a population will display genius. It's very hard to become the next Mozart if one is starving to death on the outskirts of Port-au-Prince. Having more people today is not the solution for generating more geniuses. Creating environments in which the

inherent talents of people now disadvantaged—by race or gender discrimination, poverty, or malnutrition—can be fully expressed, is.

Feeding the world's population is a problem of distribution, not supply.

Of course, if everyone shared food resources equally and no grain were fed to animals, all of humanity could be adequately nourished today. Unfortunately, such scenarios are irrelevant. Although people in developed countries could eat lower on the food chain—that is, by consuming less meat and more grain—and might be willing to make such sacrifices to improve the environment, it is as unrealistic to think we will all suddenly become vegetarian saints as it is to think we will suddenly trade in our cars for bicycles or go to bed at sunset to save energy.

But even if everyone *were* willing to eat a largely vegetarian diet today, with only a small supplement from fish and range-fed animals, and food were equitably distributed to everyone, today's harvests could feed about 7 billion such altruistic vegetarians, according to calculations by the Alan Shawn Feinstein World Hunger Program at Brown University and our group, the Center for Conservation Biology, at Stanford. Since the world's population is nearly 6 billion already, that is hardly a comforting number.

We needn't worry about future food supplies because scientific breakthroughs (as yet unimagined) will boost grain yields around the world.

Analyses of food-production trends over the past few decades suggest that there certainly *is* cause to worry about maintaining food supplies. While it is true that the most important indicator of human nutrition, world grain production, has roughly tripled since 1950, what food optimists overlook is that the Green Revolution has already been put in place in most suitable areas, and most of the expected yield gains have been achieved. Consequently, grain production increases have failed to keep up with population growth since 1985, and we've seen no productivity gains in absolute terms since 1990. Meanwhile, grain reserves have shrunk severely. A new kit of tools to expand food production is required to carry us into the future, yet no such kit appears to be on the horizon. And even if some unanticipated breakthrough were to be made, it would take years if not decades to develop and deploy new crop varieties—years during which demand would continue rising as the population expanded.

Fables About the Atmosphere and Climate

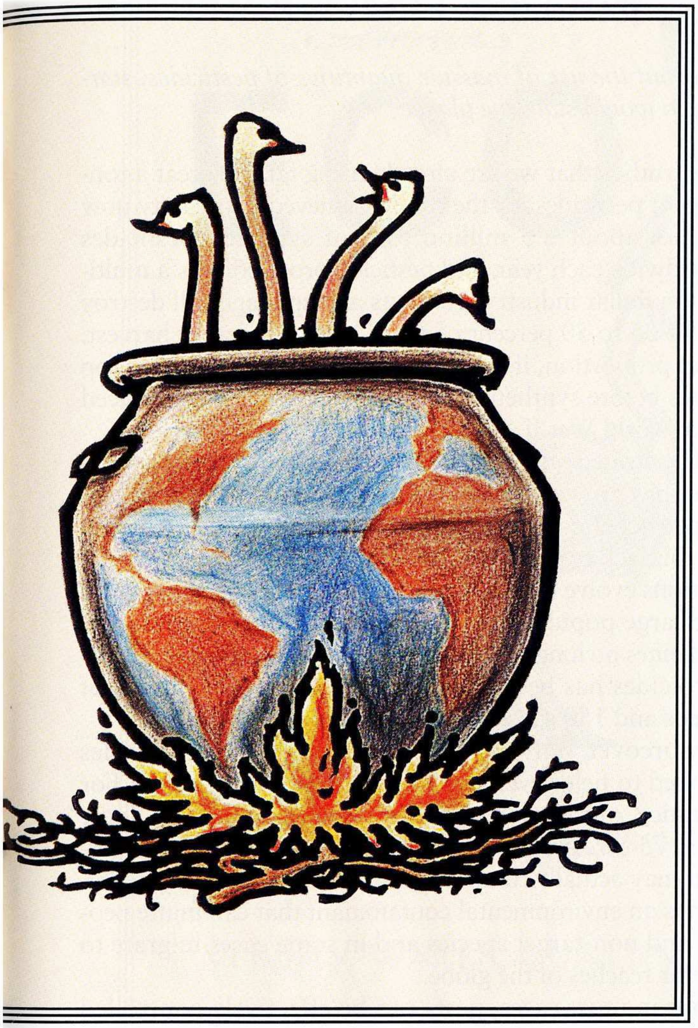
There is no evidence that global warming is real.

The climatic system is exceedingly complex and not

> PLANTS AND ANIMALS IN OUR LIFE-SUPPORTING ECOSYSTEMS CAN'T JUST PUT ON LIGHTER SHIRTS WHEN THE HEAT FROM GLOBAL WARMING BECOMES TOO MUCH FOR THEM.

entirely understood, but some facts are indisputable. First, scientists have known for more than a century that releasing carbon dioxide could add to the greenhouse effect caused by the gaseous composition of earth's atmosphere. The atmosphere contains an array of natural greenhouse gases—including water vapor, carbon dioxide, and methane—that are relatively transparent to the incoming short-wavelength energy of sunlight but relatively opaque to the long-wavelength infrared energy radiated upward by the sunlight-warmed earth. The greenhouse gases and clouds together absorb most of this outgoing infrared energy and reradiate some of it back toward earth, thus functioning as a heat-trapping blanket over the planet. The naturally occurring concentrations of these gases are enough to raise earth's average surface temperature to about 59 degrees F. Without greenhouse gases, it would be about 0 degrees, the oceans would be frozen to the bottom, and life as we know it would be impossible.

Second, scientists also know that humanity is adding to the greenhouse effect—that the atmospheric concentration of carbon dioxide in 1992 was some 30 percent above



preindustrial levels, and the concentration of methane has increased by 145 percent. Both gases are natural atmospheric constituents whose concentrations have fluctuated substantially in geologic history. But analyses of air trapped in ice cores from the Antarctic and Greenland ice caps show that today's levels are by far the highest concentrations of these greenhouse gases in at least the past 160,000 years. Moreover, nitrous oxide, another greenhouse gas, has increased about 15 percent over its preindustrial level. And chlorofluorocarbons (CFCs)—the ozone-destroying chemicals—also contribute to the greenhouse effect.

Thermometers worldwide have documented nearly a full 1-degree rise since the nineteenth century. Furthermore, a consensus has formed in the climatological community that a "discernible signal" of anthropogenic warming is beginning to emerge from the "noise" of natural climatic variation. In fact, the 1995 report of the scientific committee of the Intergovernmental Panel on Climate Change (IPCC) stated that based on the warming recorded over the past century, and especially in recent decades, "the balance of evidence suggests that there is a discernible human influence on global climate."

Global warming exists only in computer simulations.

The IPCC's conclusion was, indeed, based primarily on a new generation of computer simulations. But the results were also based on detailed comparisons with actual temperature records. Moreover, the total body of evidence that the planet is warming is now overwhelming. For example, surface-temperature records, even when corrected for the effects of urban "heat islands" (areas artificially heated by structures such as buildings and parking lots), show that the 10 warmest years in the past 140 years have all occurred since 1980. And the most recent satellite measurements show that shrinkage in Arctic sea ice, another expected result of global warming, accelerated significantly between 1987 and 1994.

Even if the concentration of carbon dioxide doubled, since it is responsible for only 1 percent of the greenhouse effect it wouldn't contribute to global warming.

By itself, a doubling of CO_2 (which, incidentally, accounts for some 10 to 25 percent of the natural greenhouse effect, not 1 percent) would warm earth by less than 2 degrees F. But therein lies the power of positive feedback. A 2-degree rise in temperature would cause more water to evaporate from the oceans and thus contribute additional water vapor to the greenhouse effect, resulting in a final warming most climatologists project to be a little less than 4 degrees. But if the complicating ice and cloud feedbacks are added in, models suggest that anywhere from 3 to 9 degrees of warming would result from a doubling in CO_2 levels. Scientists cannot make more accurate predictions at the moment because of uncertainties surrounding the feedback processes, yet most think the upper limit represents ecological disaster. For example, 9 degrees is about the difference in global average temperature that separates today's climate from that of the last ice age, when the present site of New York City was visited by a mile-thick glacier.

If the average mean temperature of the world were to rise a few degrees in the next century, we could simply wear lighter clothes and use more air-conditioning.

The idea that the primary reason to be concerned about global warming is that our backyards will be a little hotter during the summer barbecue season is as pervasive as it is wrong. The larger problem is that climate change could seriously disrupt a food-production system that already is showing signs of stress. Other potential problems include sea-level rise, which would result in coastal flooding and salinization of groundwater, as well as more intense storms. Finally, natural ecosystems—our life-support systems—will have great difficulty adjusting to rapid

climate change. The trees in southern forests can't just fly up to New England or put on a lighter shirt when the heat becomes too much for them.

CFCs can't rise 18 miles into the atmosphere to deplete the ozone layer because they are made from molecules that are 4 to 8 times heavier than air.

This statement reveals an outrageous misconception about the dynamics of the atmosphere. Gases of the atmosphere are not layered like a lasagna. If they were, the lowest few feet of atmosphere would consist of krypton, ozone, nitrous oxide, carbon dioxide, and argon. Above that would be a thick layer of pure oxygen, and above that an even thicker layer of pure nitrogen followed by water vapor, methane, neon, helium, and hydrogen. In fact, the atmosphere undergoes dynamic mixing, dominated by motions of large air masses, which thoroughly mixes light and heavy gas molecules. Because of this mixing, CFCs have been detected in literally thousands of stratospheric air samples by dozens of research groups all over the world.

The chlorine in CFCs is not likely to deplete the ozone layer because volcanoes pump out 50 times more chlorine annually than an entire year's production of CFCs.

Mount Erebus *does* pump out 50 times more chlorine per year in the form of hydrogen chloride (HCl) than humanity adds in CFCs. But the statement is irrelevant to depletion of the ozone layer because much of the HCl released by volcanoes is dissolved in the abundant steam that is also emitted and is thus quickly rained out. Unfortunately, unlike HCl, CFCs are not water soluble and thus cannot be washed out of the atmosphere until they have been broken down. And by then, they will already have done their damage to the ozone layer.

If there were, in fact, some reduction in the ozone layer, we could simply wear more hats and sunscreen lotion to avoid skin cancer.

The direct effects of a thinning of the ozone layer—which include not only increased rates of skin cancer (including lethal melanomas) but also disruptions of the immune system—could, of course, be partially avoided by increased use of hats and sunscreen. But rubbing lotions on earth's plants and animals would be required as well, since the most important threat from ozone depletion is to natural and agricultural ecosystems. Increases of ultraviolet-B radiation could significantly reduce yields of major crops and has been shown to have other significant adverse effects—such as mutation and immune-system impairment—in a wide variety of plants, animals, and microorganisms.

Fables About Toxic Substances

Without the use of massive quantities of pesticides, starvation would stalk the planet.

The truth is that we are already using far too great a tonnage of pesticides for the results achieved. Humanity now applies about 2.5 million tons of synthetic pesticides worldwide each year, and pesticide production is a multibillion dollar industry. Yet pests and spoilage still destroy about 25 to 50 percent of crops before and after harvest. That proportion, if anything, is higher than average crop losses before synthetic pesticides were widely introduced after World War II.

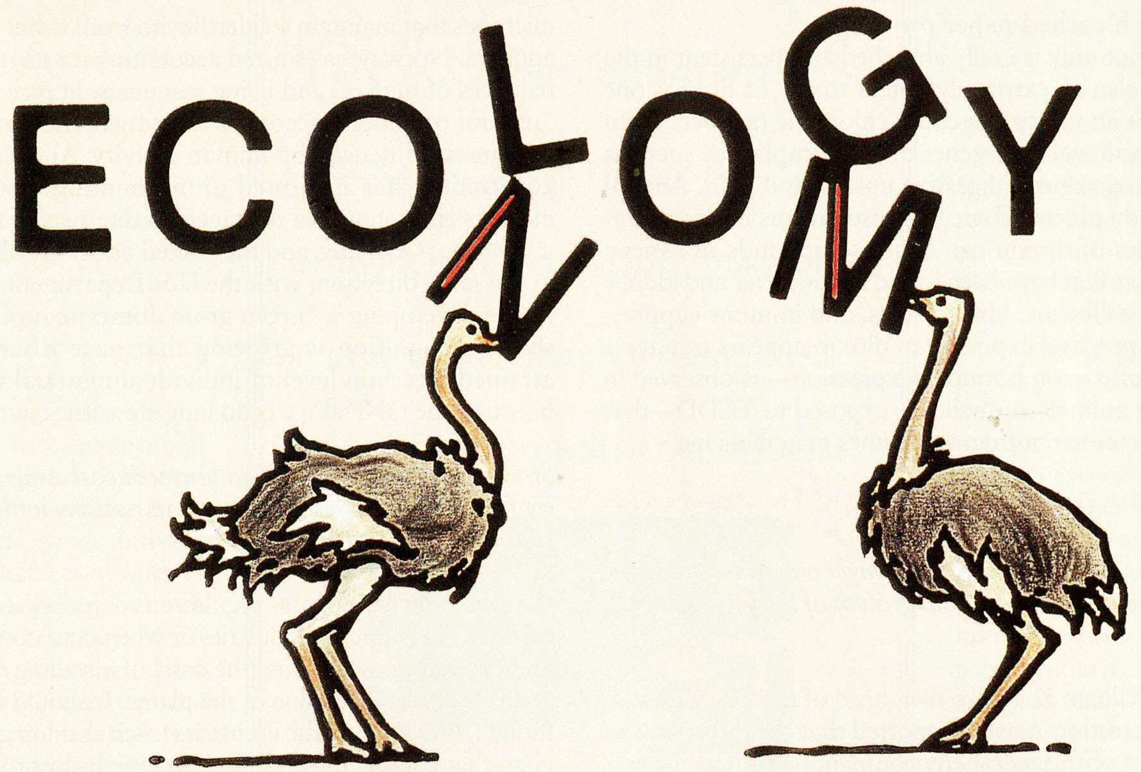
The strategy of large-scale broadcast spraying of pesticides has proven a poor one—except from the standpoint of petrochemical-company profits. An important reason for this lack of success is the rapidity with which pest populations evolve resistance: aided by short generation times and large populations, more than 500 species of insects and mites no longer respond to pesticides, and resistance to herbicides has been noted in more than 100 species of weeds and 150 species of plant pathogens.

Moreover, only a small proportion of the pesticides applied to fields ever actually reaches the target pest. For instance, of those delivered by aerial crop dusters, some 50 to 75 percent miss the target area and less than 0.1 percent may actually reach the pest. The remainder by definition is an environmental contaminant that can injure people and non-target species and in some cases migrate to the far reaches of the globe.

Yet in most cases, pests can be effectively controlled without heavy application of pesticides by using more biologically based methods. Known as integrated pest management (IPM), this approach involves various strategies such as encouraging natural enemies of pests, developing and planting pest-resistant strains of crops, fallowing, mixed cropping, destroying crop wastes where pests shelter, as well as some use of pesticides. IPM is generally vastly superior to chemical-based pest-control methods from both economic and environmental perspectives.

Indonesia, for example, has had remarkable success with IPM. In 1986, responding to the failure to chemically control the brown planthopper, a presidential decree banned 57 of 66 pesticides used on rice. Pesticide subsidies, which were as high as 80 percent, were phased out over two years, and some of the resources saved were diverted into IPM. Since then, more than 250,000 farmers have been trained in IPM techniques, insecticide use has plunged by 60 percent, the rice harvest has risen more than 15 percent, and farmers and the Indonesian treasury have saved more than $1 billion.

Pesticide use no doubt could be greatly reduced everywhere by wider adoption of IPM, which relies on synthetic pesticides as a scalpel only when needed rather than a bludgeon. Relaxing cosmetic standards on foods (such as



ECONOMISTS REMAIN IGNORANT OF LOSSES IN BIODIVERSITY, WATER QUALITY, AND OTHER CRUCIAL RESOURCES BECAUSE THESE ITEMS ARE NOT PRICED BY MARKETS.

allowing signs of minor insect damage) might also lead to reductions in pesticide use, as could the recent shift in public preferences toward "organically grown" foods. In fact, Americans increasingly distrust toxic chemicals, as is indicated by soaring sales of organically grown fruits and vegetables, which doubled to $7.6 billion from 1989 to 1994.

Overall, pesticide use in the United States could be reduced by 50 percent for a negligible increase (less than 1 percent) in food prices, according to calculations made in 1991 by the authors of the *Handbook of Pest Management in Agriculture*. Such a reduction could prove to be a great bargain if, as some scientists think, exposure to pesticide residues can impair the human immune system. And in view of today's deteriorating epidemiological environment, in which new diseases are emerging and drug-resistant strains of bacteria are causing resurgences of diseases once believed conquered, any loss of immune function should be taken seriously.

Exposure to dioxin is now considered by some experts to be no more risky than spending a week sunbathing.

Of course, with the increase in ultraviolet radiation reaching the earth's surface because of depletion of the ozone shield, a week of sunbathing is hardly a risk-free activity. But, more seriously, despite a recent barrage of misinformation, plenty of evidence shows that dioxin is a very dangerous chemical, especially in one of its more common forms, known by its chemical shorthand as TCDD.

Dioxin is a byproduct of the combustion of chlorine-containing substances—which are commonly formed when plastics are burned in incinerators and during the manufacture of the herbicide 2,4,5-T—and used in some industrial processes such as bleaching paper. People can absorb tiny amounts of dioxin by eating food contaminated by paper containers, by breathing air polluted with emissions from waste incineration, or handling some her-

bicides or bleached paper products.

Dioxin not only is easily absorbed and persistent in the body, it is also an extremely potent toxin. As little as one billionth of an ounce can cause chloracne (a severe form of acne) and various generalized complaints such as headaches, dizziness, digestive upsets, and pain. Animal studies and epidemiological investigations indicate that larger doses of dioxin can cause some kinds of cancer. Other effects that have been found include liver and kidney problems, stillbirths, birth defects, and immune suppression. And prenatal exposure to dioxin appears to have a variety of effects on hormone expression—as observed in laboratory animals and wildlife exposed to TCDD—that are sometimes feminizing, sometimes masculinizing.

Fables About Economics and the Environment

The United States can't afford stronger environmental protection; it would interfere with growth of the gross national product.

In 1990, William K. Reilly, then head of the U.S. Environmental Protection Agency, reported that the direct cost of compliance with federal environmental regulations was more than $90 billion per year—about 1.7 percent of the nation's GNP. But Reilly also pointed out that, during the two decades when the United States made substantial environmental progress, "the GNP increased by more than 70 percent." Thus, at worst, it seems that environmental regulation may slightly slow growth in the most commonly used measure of economic progress.

But that said, it should be noted that there is a growing distrust of the ability of GNP to mirror such progress, or more specifically, the enhancement of social well-being assumed to go along with it. In fact, between 1957 and 1992, although U.S. per-capita income doubled, the percentage of people considering themselves "very happy" declined from 35 to 32 percent.

One of the most prominent critics of GNP as an indicator of well-being has been economist Herman E. Daly of the University of Maryland, formerly with the World Bank. Daly has suggested a new measure of economic well-being, the index of sustainable economic welfare (ISEW), which attempts to incorporate environmental factors including depreciation of "natural capital," such as soil lost to erosion, in its calculation. Between 1951 and 1990, the U.S. per-capita GNP in inflation-adjusted dollars more than doubled, whereas the ISEW grew considerably less than 20 percent and actually declined slightly between 1980 and 1990. "Economic welfare has been deteriorating," Daly says, largely because of "the exhaustion of resources and unsustainable reliance on capital from overseas to pay for domestic consumption and investment."

Other nations are also actively seeking better indicators of human satisfaction, especially those that include the critical factor of depreciation of natural capital, from the microbes that maintain soil fertility to fresh water stored in aquifers. Norway has started accounting for its remaining balances of mineral and living resources. France now has "natural patrimony accounts" that track the status of all resources influenced by human activity. And the Dutch government has instituted an accounting system that includes environmental damage and the costs of repairing it. Sweden, Germany, and the United States are all moving in the same direction, with the U.S. Department of Commerce developing a "green gross domestic product." In short, recognition is growing that once a nation has attained a certain level of individual material comfort, boosting the GNP alone is no longer a sufficient aim.

Stricter environmental regulations will cost American jobs by forcing industries to relocate in nations with weaker standards.

Certainly environmental regulations can cost some jobs, especially in extractive industries or when outdated factories are forced to close because the costs of installing emissions controls exceed the value of the plants. It should be noted, though, that some of the industries (such as mining and logging) that complain the loudest about jobs lost to environmental regulation are of the boom-and-bust variety—set to move on anyway when local resources are depleted.

Other companies pressed by regulations may indeed choose to relocate to nations with weaker environmental laws (and cheaper labor). But as they do, other new jobs are often created, such as in high-tech businesses that favor areas where environmental quality is high, both because clean air and water are essential for their operations and because a healthy local environment helps them attract skilled labor. Moreover, even if factories required to install pollution-control equipment close down and throw their employees out of work, others will purchase smokestack scrubbers, thus creating jobs in firms that make such equipment. Overall, environmental protection is not a major cause of job losses and can be a significant source of new jobs.

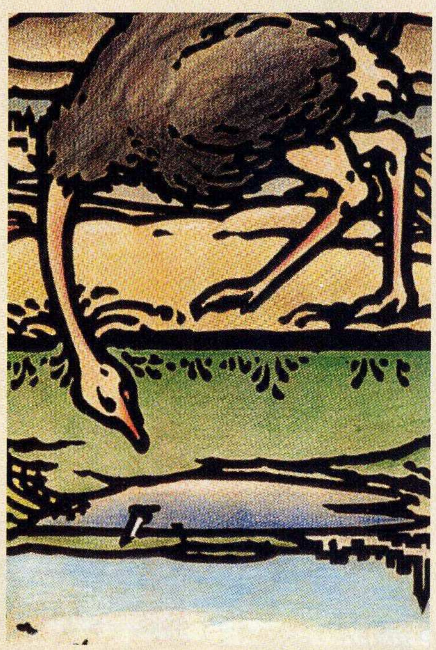
Economics, not ecology, should guide policy decisions.

A politician who says something like, "The time has come to put the economy ahead of the environment," clearly doesn't understand that the economy is a wholly owned subsidiary of natural ecosystems, and that the natural environment supplies humanity with an indispensable array of goods and services. In fact, expressed in standard economic terms, the value of ecosystem services is enormous. For example, the ability of the ecosystem to control pests could be worth $1.4 trillion annually, since without natural pest control there could be no production of agricultural crops. Ecosystem services might be valued at a total of about $20 trillion per year—almost equal to the gross global product. But these valuations only hint at the

actual value of the services, for without them there would be no human society to enjoy their unsung benefits.

All economists understand that economics is supposed to seek wise ways to allocate resources to meet human needs. As traditionally practiced, however, economics has often considered only the delivery of conventional material goods and services while ignoring environmental goods and services. That economics is not a wise guide for environmental policy decisions is underlined by economists themselves, who say they detect few "signals" indicating serious environmental problems. They are, of course, waiting for price signals reflecting shortages of resources while remaining ignorant of the depletion of many of the most critical resources such as biodiversity, water quality, and the atmosphere's capacity to absorb greenhouse gases without catastrophic consequences, which are not priced by markets.

GRASSROOTS INITIATIVES SUCH AS CURBSIDE RECYCLING ARE UTTERLY INSUFFICIENT STEPS THAT MAY ONLY DIVERT ATTENTION FROM MORE BASIC ENVIRONMENTAL ISSUES.



One Planet, One Experiment

A quick review of some compelling statistics reveals how wrong—and indeed how threatening to humanity's future—proponents of the notion that we have nothing to worry about can be. The roughly 5-fold increase in the number of human beings over the past century and a half is the most dramatic terrestrial event since the retreat of ice-age glaciers thousands of years ago. That explosion of human numbers has been combined with a 4-fold increase in consumption per person and the adoption of a wide array of technologies that needlessly damage the environment. The result is a 20-fold escalation since 1850 of the pressure humanity places on its environment, as indexed by energy use, the best single measure of a society's environmental impact. Despite such ominous trends, the antienvironmental proponents continue to hammer away in print and over the airwaves, sowing confusion and doubt in the minds of many citizens about the seriousness—if not the very existence—of environmental deterioration. Thus efforts on behalf of the environment have been limited mainly to grassroots initiatives such as curbside recycling, ecotourism, and enthusiasm for anything "organic." While we applaud such endeavors, they are utterly insufficient steps that may divert attention from much more basic issues. Instead, society needs to take a longer view and recognize that to be sustainable, the economy must operate in harmony with earth's ecosystems.

Civilization's highest priority must be lowering the pressure on those vital ecosystems, seeking a sustainable food-population balance, and safeguarding human health against global toxification and emerging pathogens alike. Achieving this will require humanely reducing the size of populations worldwide by lowering birthrates to below death rates, reducing per capita consumption among the rich to make room for needed growth in consumption among the poor, and adopting more environmentally benign technologies.

Global society is running a vast and dangerous experiment. If the experiment goes wrong, there will be no way to rerun it. In the end, we can only hope that science and reason will prevail and that the public and political leaders will heed its warnings.

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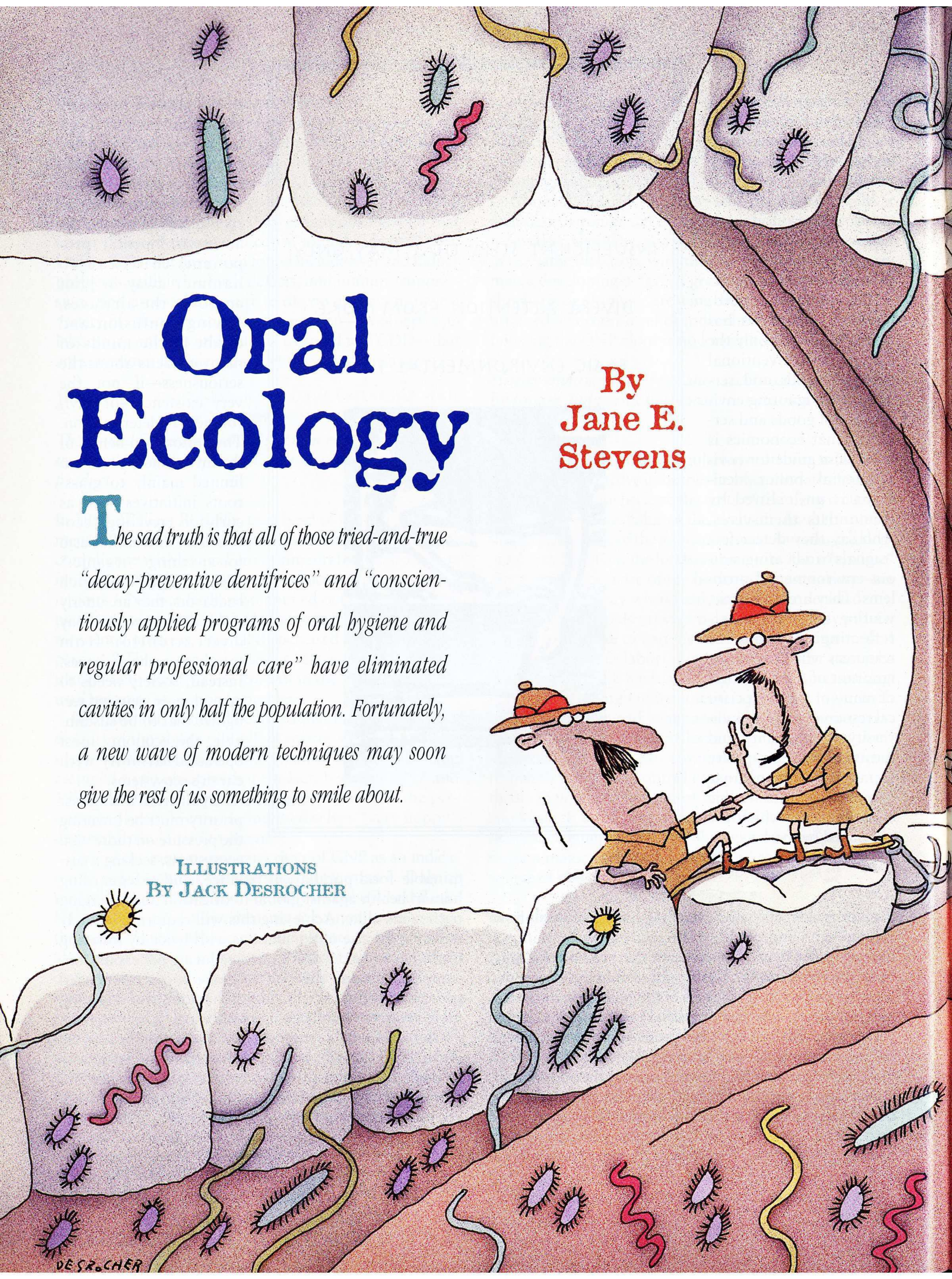
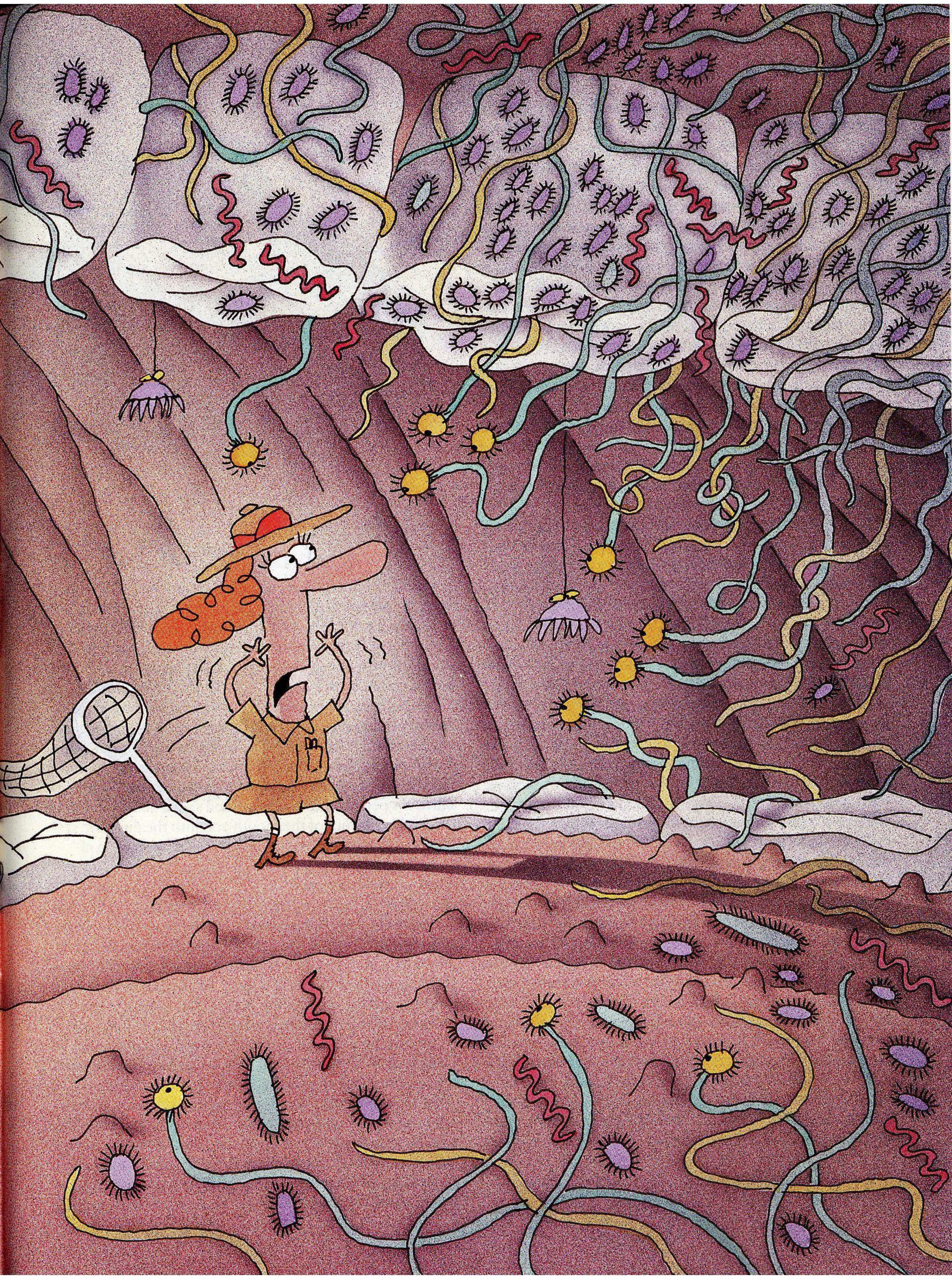


Oral Ecology

By Jane E. Stevens

The sad truth is that all of those tried-and-true "decay-preventive dentifrices" and "conscientiously applied programs of oral hygiene and regular professional care" have eliminated cavities in only half the population. Fortunately, a new wave of modern techniques may soon give the rest of us something to smile about.

Illustrations By Jack Desrocher



THE next time you kiss someone, think about this: in your mouth, and in the mouth of every adult, live more than 400 different species of microorganisms, mostly bacteria. Billions and billions of them grow in layers, crowded together and wrapped cozily around each other, on every slimy surface, dark nook, and inviting cranny. It's enough to make a body want to keep lips permanently pursed.

With an average temperature of about 95 degrees, a saliva-induced humidity of 100 percent, and regular stoking with sugar and other simple carbohydrates—manna from bacterial heaven—the mouth provides a home for such a diversity of species that it could be called the tropical rainforest of the body. "In one mouth, the number of bacteria can easily exceed the number of people who live on earth," says Sigmund Socransky, a dental researcher at the Forsyth Dental Center in Boston, Mass. "In a clean mouth, 1,000 to 100,000 bacteria live on each tooth surface. A person who doesn't have a terribly clean mouth can have 100 million to 1 billion bacteria growing on each tooth."

These facts are more useful than fodder for cocktail party chatter. An entire branch of dental research has grown up around "oral ecology"—the study of the relationships among the inhabitants of this minute jungle ecosystem—to develop the next generation of weapons in the fight against tooth and gum disease.

Since 1959, when scientists isolated a species of infectious bacteria that causes most cavities, a national campaign to reduce tooth decay has focused on brushing, flossing, and adding fluoride to water supplies, toothpaste, and mouthwashes. Fluoride, a chemical that appears naturally in groundwater in many areas of the world, quickly bonds with the tooth's enamel to maintain its smooth crystalline surface and deter bacteria from gaining a toehold.

These dental hygiene methods have worked so well that today 51 percent of U.S. children under 12 have no tooth decay. However, many of the remaining 49 percent have severe forms of cavities that are difficult to control, even with the best dental hygiene. And other problems challenge dental researchers. Periodontal disease—infection of the gums that is caused by about a half-dozen bacterial species—affects millions of adults and children. People with Sjogren's syndrome, an auto-immune disease of unknown origin that causes severe drying of the mouth, eyes, and other mucosal surfaces, have serious problems with tooth decay, as do many people whose saliva glands stop functioning after certain medical procedures.

Over the last 20 years, modern biotechnology, including genetic engineering and techniques to study anaerobic bacteria—those that live without oxygen and cause most periodontal disease—have enabled oral ecologists such as

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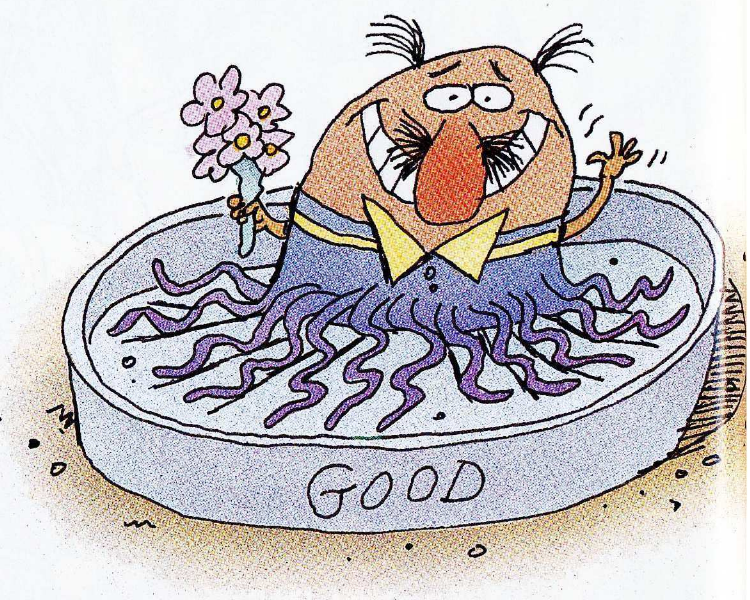


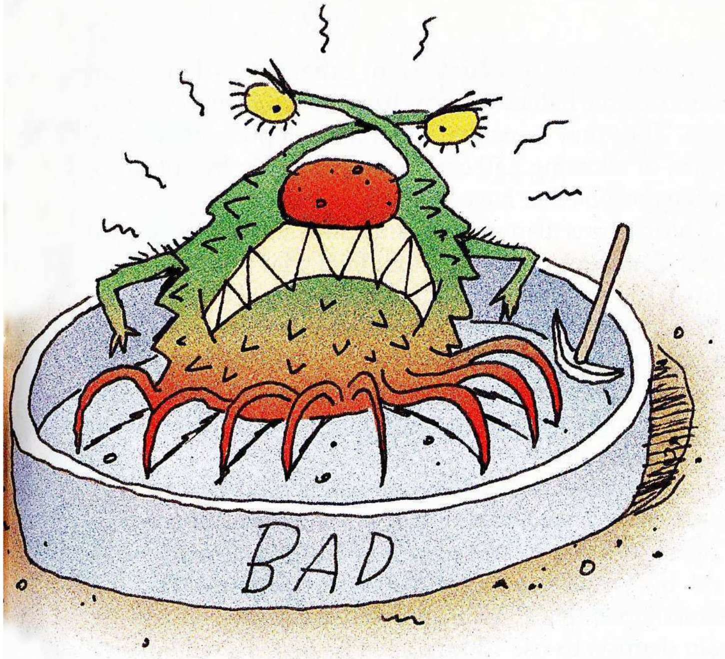
Socransky to identify some of the organisms. They have not only pinpointed about a dozen species of bacteria living in the mouth that can cause infections in the teeth and gums, but they also have made significant strides in understanding how these organisms colonize the mouth and how they are transmitted from one person to another.

Researchers are now applying their new knowledge to develop techniques that prevent the organisms from gaining residence in the first place, or to force them out using innocuous strains or new antibiotics once they've already settled in. They are also attempting to create artificial saliva for people with compromised saliva glands to sluice harmful germs out of the mouth and into the digestive system before they can stick to the teeth and gums.

Microscopic Ecosystem

Researchers have determined that the mouth's microorganisms have evolved along with the human species, probably for as long as it has existed. In exchange for living in their tropical paradise, the mostly beneficial bacteria help fend off disease-producing germs that attempt to infiltrate the mouth from the outside world. For example, some beneficial bacteria produce organic acids, such as proprionic and buteric acid, that kill organisms responsible for a number of intestinal problems.

Yet when human babies pop into the world, their wails of greeting burst from sterile mouths. "Within minutes to hours, however, they are colonized with organisms that stay with them until they die," says Socransky. These bacteria, yeast, viruses, and protozoa, most of which are harmless, enter from anything



Although diets vary the world over, dental researchers have found the same microorganisms —some helpful, some harmful— in human mouths no matter where people live.

that makes contact with a baby's mouth: air, breast, bottle nipple, thumb, and other objects.

The growth of organisms in the mouth follows the classical pattern of ecological succession—the way bare land eventually turns into thick jungle. A few pioneer species settle first, creating a habitat friendly to other species, which then, too, move in. When the first baby teeth push through the gums, another set of species—including the dreaded Streptococcus mutans, the bacteria believed responsible for most tooth decay—takes hold. During puberty, the composition of saliva changes, so that still another group of organisms immigrate and flourish. By the time humans reach adulthood, their mouths harbor what's known as a climax community—a complex group of organisms, each with its own preferred microhabitat.

Although diets vary the world over, dental researchers have found the same organisms in human mouths no matter where people live. Some species live only on the cheeks. Others prefer the back of the tongue versus the front, especially the group of anaerobic bacteria that live in the crevices of the tongue and emit hydrogen sulfide, the origin of most severe bad breath. Another group will survive only on the palate. And the teeth themselves provide a plethora of living options—surfaces open to the outside world, sides facing the back of the mouth, a strip along the edge of the gums, and the gloomy, wet, oxygen-deprived spaces between the gums and the teeth.

Saliva, the amazing fluid that keeps this ecosystem in balance, harbors its own collection of bacteria, as well as a host of other substances. Bicarbonate ions buffer the tooth-decaying acids produced by harmful bacteria such as S. mutans. Phosphate and calcium ions supersaturate saliva and continually repair the microscopic chinks made in the teeth by the bacteria's acid.

Saliva also contains antibacterial agents, such as lysozyme, which kill bacteria by opening up their cell walls. About 60 proteins float around in saliva. Some of them actually provide nutrients for bacterial growth while others lubricate the mouth and cause bacteria to stick together in such large clumps that they can't adhere to tooth surfaces and are easily washed away. Saliva even contains antiviral components. In fact, researchers at the National Institute for Dental Research, who have found that the AIDS virus does not live in saliva, are trying to isolate a substance that they believe may be effective against the AIDS virus.

Most of the time, the inhabitants of the mouth live in more or less perfect harmony. "Congress should take lessons from the mouth," says Yolanda Bonta, manager of clinical research at Colgate Oral Pharmaceuticals in Piscataway, N.J. But, like breakdowns in budget talks that sometimes lead to government shutdowns, sometimes things go to hell in a handbasket in the mouth, too.

Indeed, ecological conditions in the mouth are never stable. People change their diets, lose teeth, have crowns or false teeth put in, or take drugs that affect certain microorganisms. "For example, an epilepsy medication causes overgrowth of gums," says Socransky, "and that changes the microbiota." Radiation of the head and neck for cancer treatment as well as a host of medications also cause a drastic drop in saliva production, allowing bacteria to run rampant.

Changes also occur after every meal, after every brushing and flossing, even every time we swallow, as millions

ELECTRON MICROGRAPH OF BACTERIA ON A HUMAN TONGUE.

of bacteria lose their grip on tooth surfaces and tumble down the throat. During a night's sleep, when saliva production drops to near zero, bacteria, like the minions in the "Fantasia" version of Moussorgsky's "A Night on Bald Mountain," revel in their freedom and multiply with abandon until the dawn.

Abundant sugar can power S. mutans into a frenzy of activity. In fact, while some strains of S. mutans produce natural antibiotics against the bacteria that cause strep throat, and were probably useful in the mouths of people of primitive cultures, the preponderance of refined sugars in the modern diet changed the oral landscape so drastically that S. mutans is now more harmful than helpful. As it gobbles up sugar, S. mutans produces much more acid than saliva can buffer, and the excess eats away at the minerals of tooth enamel. Without adequate brushing and flossing, plaque grows, producing calcified deposits and a cozy home for more species that do more damage. Sticky opportunistic bacteria grab hold in the newly formed holes and crevices, causing tooth decay, and no amount of salival flow will wash them off.

Preventing Colonization

In the last few years, researchers have made significant strides not only in understanding how bacteria settle into their particular niches but also in developing methods to prevent certain harmful strains from doing so. At the University of Alabama School of Dentistry, Page Caufield, a professor of oral biology, found that humans are colonized by S. mutans—the cavity-causing bacteria—during a "window of infectivity," around two years of age. At that time, S. mutans is usually passed from the primary caregivers probably as they spew saliva droplets while talking into the face of a child whose teeth are emerging. "The window opens and closes," says Caufield. "If children aren't infected by S. mutans then, another bacteria species moves in and uses that niche. People don't exchange S. mutans as adults."

In an attempt to prevent the transmission of S. mutans to children, Caufield and his team will soon begin clinical trials on 250 mothers who carry particularly harmful strains of the bacteria. Their teeth will be treated with Chlorzoin, an antimicrobial dental sealant, that can effectively block colonization of S. mutans for up to six months, during their children's window of infectivity. The researchers say that the procedure will have no effect on the other bacteria—beneficial or otherwise—that began colonizing the babies' mouths from the moment they were born. Thus they hope that the trials will prove this a safe means of allowing 250 children to live a life free of the S. mutans strains that have plagued their mothers.

Chlorzoin is also undergoing clinical trials in several other countries. The largest clinical trial involves more than 1,300 school-age children in Dundee, Scotland. The children, who have been identified as at high-risk for S. mutans, are having their teeth painted with the sealant several times over three years. Researchers hope that it will reduce S. mutans populations to a level so low that cavities will be prevented.

In the meantime, Chlorzoin, which was developed by researchers at the University of Toronto and approved as a prescription drug in Canada in 1993, is already being sold by Oralife, a Toronto-based company that has teamed up with a Canadian dental insurance company to train dentists to use Chlorzoin. The dentists will include Chlorzoin as part of a decay-prevention program in children and adults who have especially virulent strains of S. mutans or conditions such as dry mouth that exacerbate tooth decay. If the program proves successful, Ross Perry, president of Oralife, anticipates that dental sealants will soon be used in the United States.

According to Perry, approximately 10 percent of North Americans are at high risk for tooth decay, while another 10 to 15 percent are at medium risk. The amount spent on restorative dentistry by these two groups accounts for 60 percent of the total dollars spent on dentistry. "By doing this treatment over two years, S. mutans can be reduced, and adults can move down a notch in their risk factor," he says. "Before this program, insurance companies never paid for prevention. They always paid after a person was infected."

Dental Vaccines

Martin Taubman and Daniel Smith, dental immunologists at the Forsyth Dental Center, have been working on an alternate method of preventing S. mutans from colonizing children's teeth. The researchers know that humans develop antibodies to mutans streptococci (the group of bacteria containing S. mutans) when they're around three years old, after the bacteria have already colonized their teeth. People retain these antibodies as adults but never develop enough to completely wipe out the bacteria. The team's goal, therefore, is to develop a vaccine that can be given to children before their mouths are colonized by S. mutans. That way, when the bacteria infect them, the antibodies would already be present.

A vaccine that Taubman and Smith have developed thus far induces the body to produce antibodies against an enzyme produced by mutans streptococci. The enzyme—glucosyltransferase, or GTF—breaks down the sugar in food into more simple sugars—glucose and fructose. The

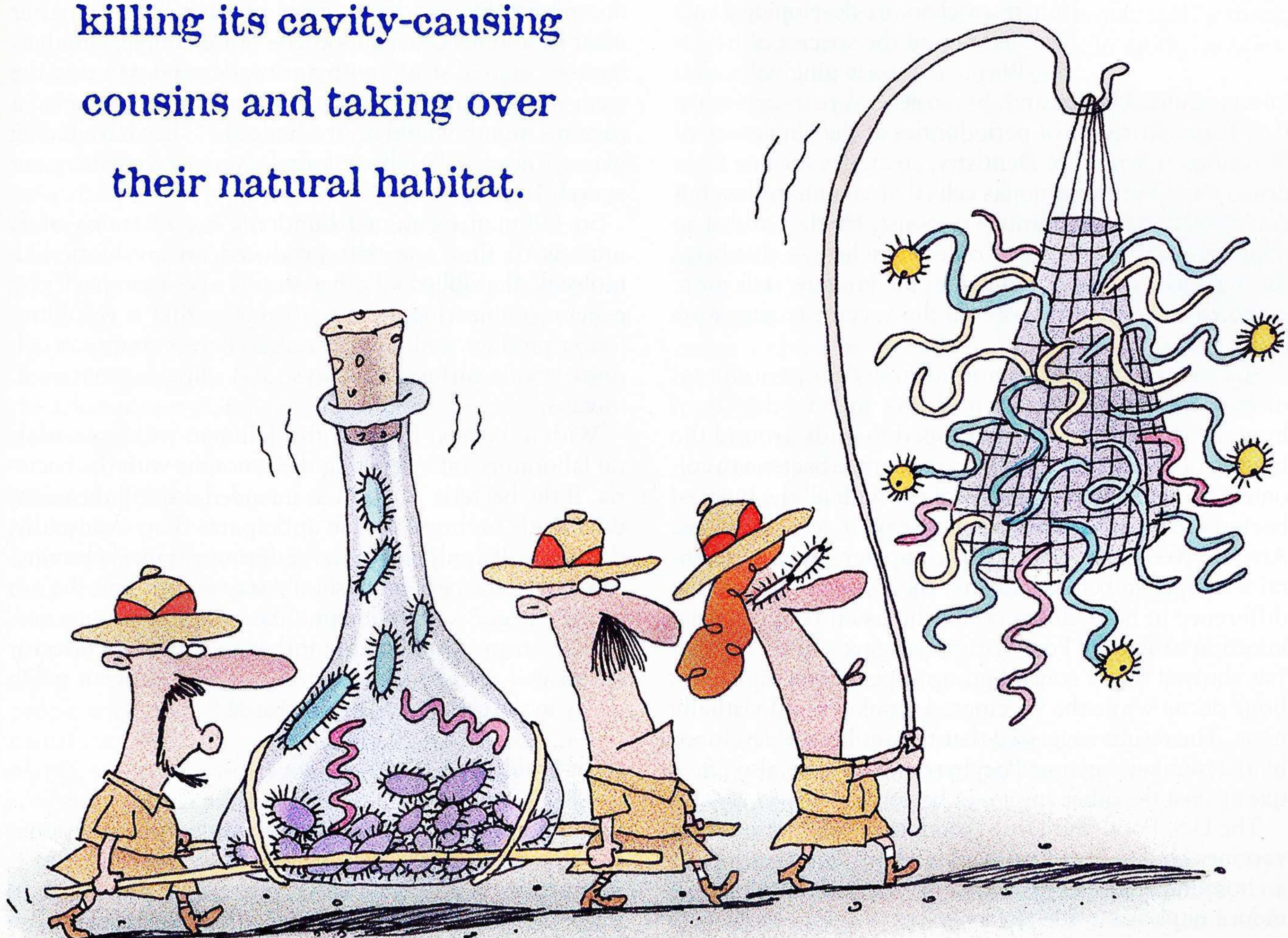
PHOTO: SCIENCE SOURCE/PHOTO RESEARCHERS

resulting simple-sugar molecule is critical because it is the substance to which bacteria bind, like dust bunnies to Velcro. Thus the enzyme helps create a mass of bacteria large enough to metabolize other carbohydrates and produce lactic acid. "You get enough bugs, you get enough acid, you produce a hole," says Taubman.

The antibodies produced by the vaccine interfere with the site on the enzyme that cleaves the complex sugars, preventing them from being broken down into the components to which the bacteria like to adhere. The vaccine was first tested on animals, who, after immunization, developed fewer cavities. It was then given to adult humans, whose immune systems have been shown to produce antibodies.

Taubman and Smith are in the process of refining the vaccine so that it can be made artificially—that is, not from the live mutans streptococci themselves, but from molecular components—but do not immediately anticipate testing it on children simply because the Forsyth Dental Center lacks the necessary medical infrastructure. They anticipate working with centers that specialize in vaccines for children to piggyback their vaccine onto those developed for other diseases.

Scientists have genetically engineered a strain of harmless bacteria that is capable of killing its cavity-causing cousins and taking over their natural habitat.



COLOR-ENHANCED ELECTRON MICROGRAPH OF BACTERIA ON A TOOTH SURFACE.

Researchers are also developing vaccines to help prevent periodontal disease. Scientists originally thought the task would be daunting because, unlike tooth decay, the disease appeared to involve the complex interactions between many species of bacteria: some bacteria live in the periodontal pocket—the space between the gums and the teeth—and interact with a second set that colonizes the tooth above the pocket.

But oral ecologists have recently discovered that most periodontal disease may be caused by just three bacteria. One species is responsible for most juvenile periodontia, while two other species cause most infection in adults. At the University of Washington, researchers are developing a vaccine for one of the species of bacteria, Porphyromonas gingivalis, that infects adults. The research began several years ago when Roy Page, professor of periodontics at the University of Washington School of Dentistry, created a vaccine from deactivated Porphyromonas cells that were harmless but could still initiate an immune response. He then added an adjuvant—a mix of oils and other ingredients—that helps the antigen last longer and makes the immune cells more responsive—and administered the vaccine to macaque monkeys.

Since most animals do not normally get periodontal disease—the only species it shows up in other than humans is beagles—Page wrapped threads around the bottom of the monkeys' teeth to encourage bacteria to colonize. He then infected the monkeys with all the types of bacteria that cause periodontal disease in adult humans. After 36 weeks, he performed a computer analysis of dental x-rays taken before and after the study to measure the difference in bone destruction, the usual result of gum infection caused by Porphyromonas gingivalis. The analysis showed that a control group experienced significant bone decay while the vaccinated monkeys had virtually none. The results suggested that the antibodies developed by the monkeys against Porphyromonas were also effective against the other species of bacteria.

The U.S. Food and Drug Administration requires that vaccines be developed from specific proteins that induce an immune response, instead of from killed cells that may induce unpleasant side effects in humans. One likely candidate is a protein on the surface of Porphyromonas called cystine protease that induces an immune response to the bacteria, and seems to cause no side effects. The FDA also prefers proteins that are made from pure antigen—that is, antigen derived directly from DNA—to reduce the chance that they will contain "impurities," or other cell components, that may cause unwanted reactions. To that end, Page is working with Marilyn Lantz, a genetics researcher at the University of Indiana, to make a recombinant version of the protein from pure DNA for further testing in monkeys. "If we get protection from cystine protease," Page says, "we'll ask the FDA to do clinical trials for safety in humans."

Displacing Bacteria

Other new research is aimed at ridding the mouth of harmful organisms that have already found comfortable habitats. At the University of Florida at Gainesville, molecular biologist and dentist Jeffrey Hillman has been using genetic engineering to develop a harmless strain of S. mutans that will replace the acid-producing varieties that occupy and cause cavities in most mouths.

In the early 1980s, Hillman and his research team isolated a type of S. mutans that metabolizes sugar but doesn't produce acid as a waste product. But no matter what he and his colleagues tried—for example, eliminating the original strain with antibiotics and painting the teeth with iodine—the S. mutans that already occupied a person's mouth would not be budged. "They have hiding places," he says. "Nobody found a way to wipe them out entirely."

So Hillman examined hundreds more strains of S. mutans to find one that produced an antibiotic-like molecule that killed all other strains of S. mutans. Using genetic engineering, he modified it so that it would no longer produce acid. This so-called effector strain can colonize tooth surfaces, he says, and wipe out native S. mutans.

Within the next few months, Hillman will begin trials on laboratory rats, infecting their mouths with the bacteria. If the bacteria perform as intended, he will then conduct trials on humans. He anticipates that, eventually, dentists will apply the bacteria during a typical cleaning. "In theory, the new strain should stay with people the rest of their lives," says Hillman. "And since S. mutans normally is transmitted from mother to child, this effector strain will also be transmitted, and will prevent tooth decay in the children of those treated."

Root Problems

Other attempts to oust offensive germs from their comfortable dwellings are taking aim at the bacteria, yeast, and protozoa that dive down tiny cracks in a tooth to infect the blood- and nerve-rich tooth roots and cause ice-pick-like stabbing pain. If root infections in certain teeth in the upper jaw are not treated, the bacteria can cause serious eye infections, even blindness. "That's why they're called eye teeth," says Kathleen Olender, an endodontist at

PHOTOS: MECKES/OTTAWA, SCIENCE SOURCE/PHOTO RESEARCHERS, INC.

the University of California-San Francisco Dental School.

Similarly, if a tooth in the lower jaw becomes severely diseased, the bacteria can travel to the throat and cause a condition called Ludwig's angina in which the larynx can swell so much that the person can't breathe, says Craig Baumgartner, chair of the Department of Endodontology at Oregon Health Sciences University in Portland. Bacteria from a tooth in an upper jaw can also spread into the pterygoid plexus, a locus of nerves and blood vessels in the face. "The bacteria can back up the veins into the brain," he says, and even cause dementia.

Baumgartner says that while endodontists see these severe infections only occasionally in the United States, they are still common in developing countries where people don't have access to antibiotics and aggressive care to surgically remove infected roots. Moreover, although root-canal procedures have been performed for hundreds of years, and today about 10 million teeth a year undergo endodontic procedures, it was not until antibiotics were developed after World War II that dentists were allowed to perform root canals in the United States because the bacterial infection in the root was often difficult to contain.

Researchers aiming to control these infections have recently identified eight species of bacteria that seem to cause most of the infections that occur in tooth roots. Their goal is to eliminate all of the bacteria in an infected root, since it is normally sterile. But because there seems to be a complex interplay among the species of infecting bacteria—a byproduct of one is used as a nutrient by another—researchers such as Baumgartner at the Oregon Health Sciences University believe that identifying and focusing on killing one or two species would upset the ecosystem to such a degree that the rest would die off. Toward that end, he and other researchers are now testing the effectiveness of individual antibiotics on targeted bacteria species.

Mimicking Saliva

Saliva provides perhaps the most effective means of ridding the mouth of harmful bacteria. Indeed, without enough saliva, the 2 million people with Sjogren's syndrome, which causes severe drying of mucosal surfaces, suffer a variety of oral infections. So, too, do millions of people whose saliva glands are affected by radiation treatments for head and neck cancers, bone-marrow transplants, some chemotherapy, or the more than 400 prescription and over-the-counter drugs that have been reported to cause mouth dryness.

Unfortunately, a quest to develop artificial saliva has proven largely unsuccessful. The main reason is that many of its components have not even been identified, says Philip Fox, clinical director of the National Institute of Dental Research (NIDR). These include the viral and bacterial components, as well as the myriad substances that aid in chewing, initial digestion, and swallowing. Researchers therefore haven't been able to replicate its physical and chemical properties, nor have they been able to identify all the ways in which it contributes to the functioning of the mouth as an ecosystem.

Until they can say exactly what saliva is, NIDR researchers such as Fox are focusing instead on other options. For people who retain some part of their saliva gland, researchers have had success with a drug, pilocarpine, that stimulates the gland to produce more saliva. They are also searching for ways to control Sjogren's syndrome through the use of steroids and other drugs that aim to calm down the immune response that shuts down saliva glands.

"We're also attempting to reengineer the saliva gland," says Fox, by using gene-transfer technology to try to reconstitute a damaged gland. In one method, NIDR researchers Brian O'Connell and Bruce Baum are using standard gene-transfer technology in which a virus that infects a cell is used to carry a gene that will cause the cell to produce a substance that its own DNA is not programmed to produce. When salivary glands have been damaged by radiation or disease, cells may still be there, but they are not water-secreting cells. In animal studies, the researchers have been able to transfer genes into cells and get them to produce water. Fox says that within two to three years, the same techniques may be able to be used on humans.

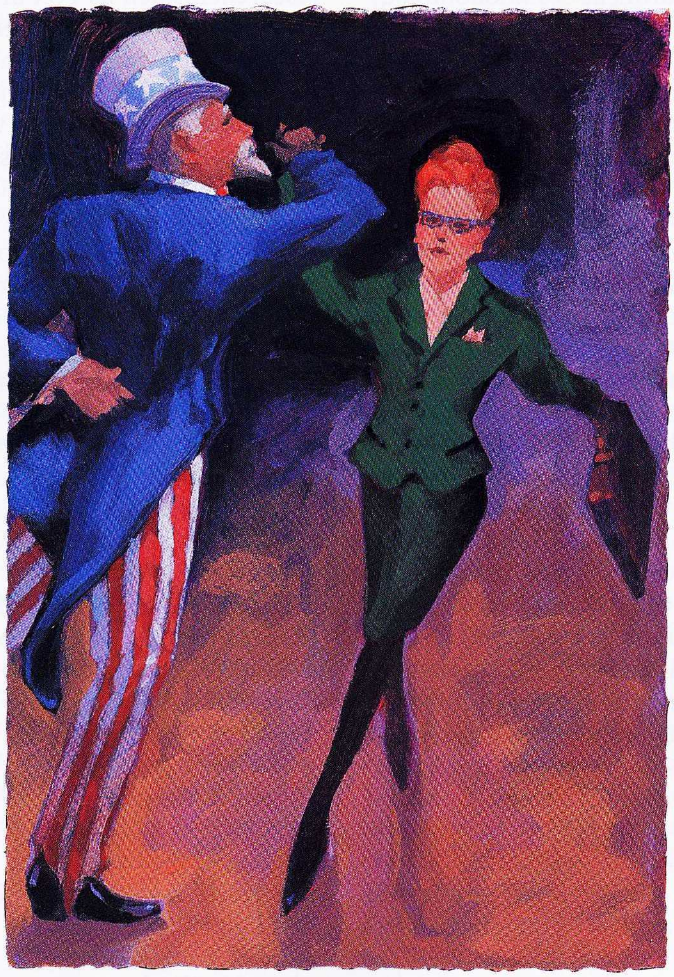
TOOTH DECAY SHOWN AT 300X MAGNIFICATION.

Because the field of oral ecology is at its beginning stages and the fruits of the new research still need to go through the long process of clinical trials, most new techniques will not see the inside of people's mouths for 5 to 10 years, say researchers. Until then, Bonta of Colgate Oral Pharmaceuticals advises that "although you can afford not to brush for 72 hours, if you pass that threshold, the bacteria will have taken hold and multiplied to such concentrations that the acid they produce has begun making holes in the teeth. Moreover, you may not be able to remove the plaque and bring the infected parts of the teeth back to health."

It's also best to brush for more than a minute, says Ernest Newbrun, a dental researcher in the University of California at San Francisco's Department of Oral Biology. That's the effort required to clean the 150 tooth surfaces found in most people's mouths and to bring the bacteria count down to a manageable and healthy 1,000 to 100,000 per tooth. ■

DAVID REJESKI

Getting Into the Swing



A casual reader of the popular press cannot help but notice that *Business Week* is beginning to look more like *Sierra* magazine. Conferences once reserved for environmental engineers and scientists are now populated by business executives proudly expounding on such themes as environmental stewardship and sustainable development. It would be easy—and incorrect—to dismiss many of these public pronouncements as corporate rhetoric chasing "green" consumers. In fact, industry has developed, and is applying, a set of managerial approaches and technical tools to create the next generation of environmental improvements.

Unfortunately, policymakers will probably either miss or misunderstand these changes. Having spent the last 25 years focused on the cheaters and laggards, we are ill-prepared to understand the motivations and the methods of the industry leaders. But policymakers who are willing to leave some cherished beliefs behind and journey into the strategic core of innovative corporations will discover the most radical restructuring of production since Henry Ford—one with far-reaching implications for the environment.

First, industry is moving into a world where many products will be designed, built, and tested before they physically exist. Whether it is chemicals or a Boeing 777, a new generation of virtual prototyping systems is allowing companies to engage in what Gary Pisano at the Harvard Business School calls "learning before doing." This practice opens up new opportunities for environmental improvement by moving decision making upstream, before the manufacturing process, before any waste or harmful pollutants reach the air, water, or landfills.

With more companies seeing environmental consciousness as a matter of self-interest, regulators need to chart a more business-friendly course.

Second, having exploited many existing opportunities for environmental improvements within the firm, more and more companies are expanding their search to encompass the entire "value chain"—from raw materials producers to suppliers to manufacturers to customers. For example, 3M and the Netherlands-based chemical company Akzo Nobel developed an environmental guide for the furniture industry—one of their major customers—to help ensure that their products were being used in an environmentally responsible manner. Motorola, when faced with the challenge of eliminating chlorofluorocarbons from its production processes, moved technical expertise upstream to its suppliers—the same strategy the company used to great advantage in its earlier efforts to raise product quality. In industries that have "outsourced" much of their production, disseminating technical expertise and environmental management skills up and down the value chain becomes the strategy of choice for making more environmentally sound products.

Finally, as customers demand more environmental information and value from producers, businesses are angling to position themselves and their products as the green choice. A recent study showed that Arm & Hammer, by providing better environmental information on its laundry detergent, was able to realize an additional $10 million in annual revenue for that product. People gravitated to the Arm & Hammer brand out of loyalty to a company whose detergent they believed would not foul the environment. The bottom line is that many companies no longer view environmental concerns as a cost of doing business but as a profit driver.

Will corporate environmental sensitivity make government's protective role passé? Hardly. Government will play an important role in disseminating information on best environmental practices, setting "baseline" standards for environ-

ILLUSTRATION: SHELDON GREENBERG

mental performance, and in measuring and reporting on the state of the environment. And as in the past, government regulations will provide incentives to gently nudge the less enlightened companies to clean up their acts. But numerous interviews with managers in innovative U.S. firms have convinced me that companies want from government something more. They are looking for attributes that characterize any good business partner: predictability, cohesiveness, and speed.

Predictability. A steady public policy is critical to corporate decision making—particularly at small companies, which often lack comfortable financial cushions. Unpredictable variations in governmental regulations and programs suppress innovation, discourage investment, and produce market uncertainties. The recent budget battles between Congress and the Clinton administration created a climate of uncertainty among those in business charged with conforming to environmental laws and responding to environmental incentives. Industry's decision making was paralyzed for months as companies waited for the dust to settle in the Washington tug of war between those who would maintain and improve upon our existing regulatory system and those who sought to reverse many of the environmental gains made over the past 25 years.

Cohesiveness. Even if stability is maintained, the existing mosaic of policies, programs, and regulations slows the ability of many U.S. businesses to turn environmental innovation into profits and competitive advantage. A better integration of policies across government agencies and among federal, state, and local decision makers would facilitate environmental leadership in industry by creating a clearer path for the commercialization of new ideas.

The multibillion-dollar market in the United States for environmental goods and services ought to encourage technology developers. But because regulatory and permitting policies differ from state to state, and even from county to county, this market is broken up into many, smaller pieces. Both the New England and Western Governors' Associations have developed reciprocity agreements among states to begin to address this problem. An example of program integration at the federal level is the new Rapid Commercialization Initiative (RCI), in which four agencies—the Environmental Protection Agency and the departments of Commerce, Defense, and Energy—work together to accelerate the introduction of environmental technologies into the marketplace. RCI helps companies find appropriate sites for demonstrating innovative ways of monitoring and controlling pollution, assists in verifying the technologies' performance and cost, and expedites permits.

Speed. Finally, public policymakers need to understand that time matters. In six to eight months—the half-life of many government permit and grant applications—entire new product lines can be developed and launched. Without significant increases in speed, the public sector risks becoming a drag on private-sector innovation. In one helpful step, the new Pollution Prevention Permits Program in Title V of the Clean Air Act allows companies to switch to environmentally superior processes without automatically triggering expensive and time-consuming modifications to their plant-operating permits. For companies making process changes every 18 to 24 months, such flexibility is critical in reducing time to market.

We will probably always need a system of environmental policies to deal with "bad actors." But ensuring that policymaking is predictable, cohesive, and time-sensitive will allow innovative and well-intentioned companies—the good actors—to focus a new generation of technical and managerial tools on environmental problems without being hamstrung by uncertainty and red tape.■

DAVID REJESKI is director of technology programs at the Environmental Protection Agency's Office of Economy and Environment. He is presently assigned to the White House Office of Science and Technology Policy.

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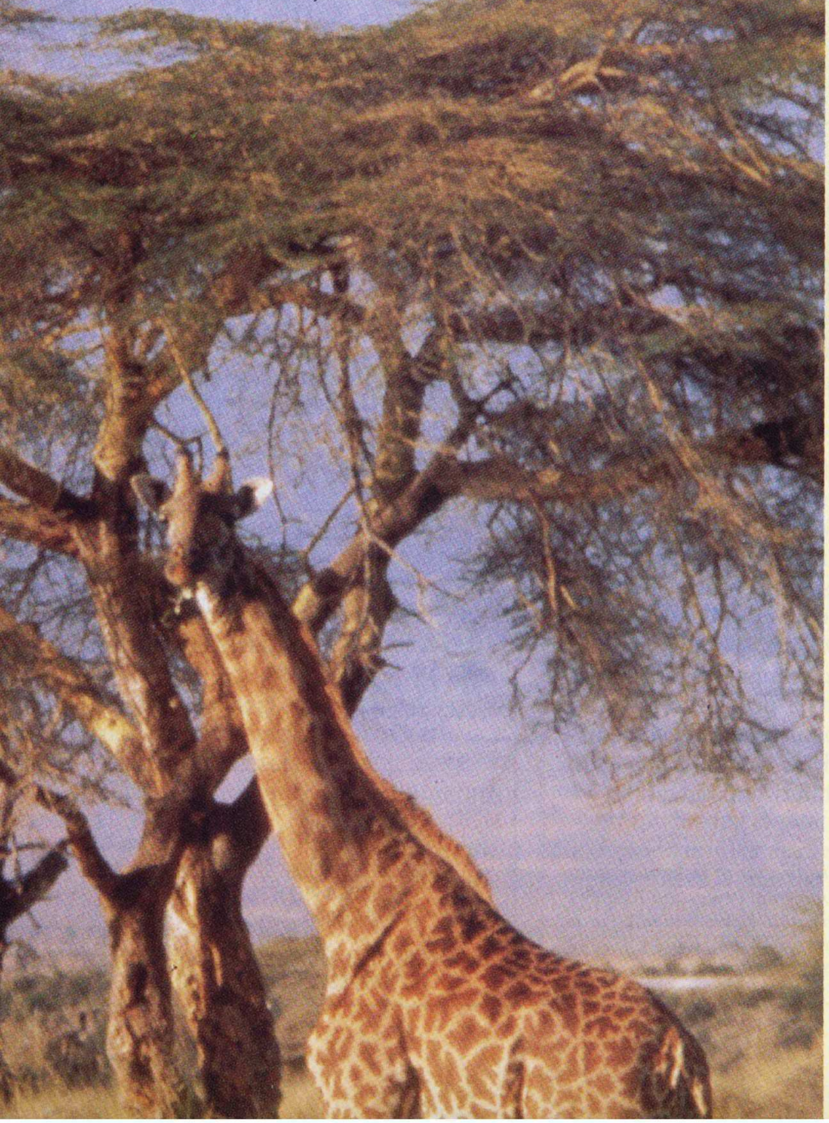
This September, explore the Ngorongoro Crater, the 100-square mile floor of an extinct volcano, 2,000 feet down—Africa's "Garden of Eden." We will also visit Lake Manyara National Park and Tarangire National Park, both home to a wide variety of wildlife, including gazelle, elephant, rhino, lion, giraffe and many bird species. ❋ Join us for a eight-day pre-extension of Mount Kilimanjaro. Hike from 3 to 6 hours each day, and witness daybreak as we reach the "Roof of Africa" at 19,340 feet!



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September 15 - 25, 1997

In Glasgow, discover the work of architect Charles Rennie Mackintosh. In the Grampian Highlands, tour the Glenfiddich Distillery, and Stirling and Ballindalloch castles. In Edinburgh, we contrast the work of Robert Adams with typical 17th-century architecture, and visit Kinloch Anderson, the leading makers of kilts and tartans for Scottish clans.

For more information on the itinerary and prices for the Tanzania Safari program contact Park East Tours at (800)223-6078, or the MIT Alumni/ae Travel Program. For more information on all of the programs above, contact the MIT Alumni/ae Travel Program, 77 Massachusetts Avenue 10-110, Cambridge, MA 02139, phone: (800)992-6749, compass@mit.edu, <web.mit.edu/alum/www/Information/Travel/>

Literary Letdown

Why is technology so conspicuously absent from the roster of the century's greatest books?

SAMUEL C. FLORMAN

LAST year, to celebrate the centennial of its founding, the New York Public Library mounted a show entitled "Books of the Century." All the librarians—from 4 central research facilities and 82 neighborhood branches—were asked to suggest books published during the past 100 years that had "a significant influence, consequence, or resonance." From more than 1,100 titles recommended, 159 were selected for the exhibition. Now, a year later, the library has issued a book summarizing the contents of the show.

Browsing through this attractively presented slim volume, I was at first enthralled. Each entry is described and justified in an informative one-page essay. Selections include works by literary greats such as Proust, Kafka, Chekhov, and Joyce; influential near-greats such as Hemingway and F. Scott Fitzgerald; and popular mass-audience writers like Zane Grey, Agatha Christie, and Stephen King. But "literature," in the usual sense, is just the beginning. The richly varied list ranges from volumes by Dr. Spock, Emily Post, and Dale Carnegie, to those by Malcom X, Churchill, Hitler, and Mao.

Combining the diversion of a parlor game with the satisfactions of a history lesson, *Books of the Century* is delightful to peruse. But when I looked at the project afresh, this time through the eyes of an engineer, my mood soured abruptly.

Science is nicely represented—in works by Einstein, Marie Curie, James Watson (*The Double Helix*), Edward Wilson (*The Diversity of Life*), and a few other volumes less well known but clearly deserving. For engineering, however, one must look under a section entitled "Economics & Technology" to find only the following three selections: *The Death and Life of Great American Cities*, by Jane Jacobs, a "sardonic critique" of mid-twentieth-century city planning; *Super Highway—Super Hoax*, by Helen Leavitt, an "impassioned polemic" against the people responsible for the interstate highway system; and *Small Is Beautiful*, by E. F. Schumacher, whose ideas about appropriate technology evolved because he was "disillusioned with Western materialism."

That's about it for engineers, unless you want to count *The Whole Internet User's Guide & Catalog*. Out of the past hundred years, these are the books chosen to represent technology and the engineering profession! Let me take a moment to regain my composure.

I will not quarrel with the selections themselves, since concern about technical progress has certainly been part of our cultural scene during the past century. Nor do I object to the inclusion, in other categories, of Rachel Carson's *Silent Spring*, Aldous Huxley's *Brave New World*, and George Orwell's *1984*. But I am moved to ask: Is there absolutely nothing significant, consequential, or resonant written in the past century that affirms technology and the work of engineers?

Interestingly enough, one of eight books that exhibit attendees cited as worthy of inclusion is *Atlas Shrugged* by Ayn Rand. This once enormously popular novel, written in 1957, describes how America's engineers, distressed by government controls and "liberalism," go on strike until the public comes to its senses. It is not, however, a book that I admire, so its addition as a footnote does nothing to assuage my gloom.

All right then, the librarians of New York might well ask: What specific books do you think should be added? This question brings to mind an effort of a decade ago, when 100 technologists and technology scholars participated in a survey to select "The Great Books in Technology." At the head of the list of 52 books was Lewis Mumford's *Technics and Civilization*, first published in 1934. Mumford helped found the field of history of technology and he championed technical creativity before becoming disenchanted in his later years with the dehumanizing influence of "the machine." *Technics and Civilization* would have been a good choice for the New York librarians.

Of the many other fine books on the technologists' list, two had the public impact that could have qualified them for the Books of the Century show. These are Tracy Kidder's *The Soul of a New Machine* and Robert Pirsig's *Zen and the Art of Motorcycle Maintenance*. Most books about technology deal strictly with hardware, sometimes rounded out by consideration of history and social influences. Kidder and Pirsig probe deeper, exploring the emotional aspect of technical work. Their books portray the excitement, joy, and spiritual satisfaction inherent in engineering—in *Soul*, the design of a new computer; in *Zen*, the immersion of ego in work with machines.

These remarkable books were celebrated by critics and also sold well. One would have thought that their success—both literary and commercial—would have inspired others to examine the same sources of human experience, but this has not happened. We can only conclude that writers' misgivings about technology—which date back at least as far as the classical age of Greece—persist to this day.

I am disappointed by the librarians of New York. But I am more disappointed by the ancient and forbidding gulf that still lies between engineering and creative literature. Perhaps calling attention to this gulf will encourage efforts to bridge it. ■

SAMUEL C. FLORMAN, a civil engineer, is the author of The Existential Pleasures of Engineering, *recently reissued in a new edition. His latest book is* The Introspective Engineer.

PHOTO: L. BARRY HETHERINGTON

Welfare "Reform" Backfires

The new welfare law creates a major disincentive to invest in productivity-enhancing technology and worker training.

BENNETT HARRISON

THANKS to a bizarre alliance between a Republican Congress and a Democratic president, almost all welfare recipients are going to have to move into "jobs" of some sort, generally paying the minimum wage. For the first time since the New Deal created Aid to Families with Dependent Children (AFDC), the federal government no longer guarantees, as a right of citizenship, assistance to poor mothers with young children.

Welfare has long been widely misperceived. Contrary to public belief, most AFDC recipients are white. And for all the hand-wringing about teenage mothers, fewer than 8 percent of AFDC parents are under age 20.

From an economic standpoint, the end of "welfare as we know it" raises both short-run and long-term questions. The most pressing concern, of course, is where the work will come from. Local governments are already wrestling with how to insert welfare recipients into their street- and subway-cleaning and child-care-assistance programs in ways that don't destroy the livelihoods of the "permanent" public employees. Everyone seems to want the private sector to provide most of the jobs. Toward that end, President Clinton proposes federal tax incentives to companies who hire from the welfare rolls.

But economists agree, with near unanimity, that such tax breaks have in the past not enticed companies to hire anyone—let alone the poorest of the poor—whom they would not have employed anyway. For successful companies, taxes simply do not constitute a large enough fraction of the cost of doing business for such discounts to matter. The most recent example of such failure was President Carter's targeted jobs tax credit, which continued into the Reagan years before Congress cut it off on the grounds that it was merely providing firms with windfall profits. At best, tax incentives might redistribute jobs from other prospective employees to the targeted group, without creating new openings. This can be a legitimate policy objective, but it is not what President Clinton is seeking.

Then there are the long-run questions. Can temporary public-service jobs—cleaning parks and buses, assisting child-care professionals, working in the clerical temp pools of government agencies—foster skills that people can apply to fruitful careers? Acquiring skills may be equally difficult in the private sector. Peter Cappelli, who chairs the management department at the University of Pennsylvania's Wharton School, and others have conducted surveys that document how cautious most companies are about investing in employee training, especially for their less educated workers. If we assume that training has at least something to do with upward mobility, how can we expect those forced off welfare to look forward to "moving on up"?

Perhaps the most serious long-term economic danger of welfare reform is that increasing the supply of cheap labor may undermine incentives to invest in productivity-enhancing technologies. Right now, high wages—whether sustained by labor shortages, union contracts, or civil service rules—pressure employers to acquire new technology and keep their workers trained. Only by raising productivity can an organization afford the high wages that prevail.

But the flood of low-cost labor that welfare reform is creating may well persuade at least some organizations to postpone technological upgrading and defer training. Rather than invest in new and more productive equipment, businesses (and government employers as well) may find it more cost-effective to hire platoons of people, pay them little, and set them to work on slow, outmoded computers, machine tools, and switchboards. To what extent this happens will depend in part on the size of the wage effect of welfare reform; the Economic Policy Institute estimates that wages could be depressed by as much as 17 percent in New York State alone.

This is not to say that technology will stand still. Some decisions regarding the introduction of new technologies have little or nothing to do with the availability of cheap labor. A company that wants to improve communication with its suppliers, for example, will still probably insist that all the players in the contracting chain introduce best-practice computer systems, software, and standards, and that they train their employees to use the new technology.

The challenge is to implement welfare reform in a way that is attentive to the dignity, incomes, and life chances of those being shoved into the (low-wage) labor market, but that also protects the hard-won gains of established workers—all without further undermining employers' willingness to invest in technology and training. That's a tall order—perhaps, in a slow-growth economy, an impossible one. But simply identifying what is at stake—economic growth rates, wage levels, investments in training and technology, the resilience of existing contracts between employers and their usual workers—makes it clear that welfare reform is about much more than "just" several million poor mothers and their children. It is about the structure and trajectory of the economy in which we all live and work. ■

BENNETT HARRISON is professor of urban political economy in the Milano Graduate School of Management and Urban Policy at the New School for Social Research in New York.

PHOTO: L. BARRY HETHERINGTON

Reviews

BOOKS

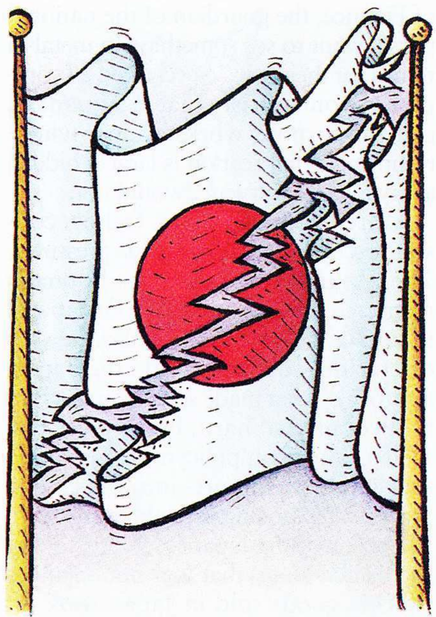
QUESTIONING JAPAN'S MIRACLE

Divided Sun: MITI and the Breakdown of Japanese High-Tech Industrial Policy
by Scott Callon
Stanford University Press, $29.50

BY JACOB PARK

FOR over two decades, economists and political scientists have cited Japan to show just how effective a strong, well-designed industrial policy can be. Chalmers Johnson, president of the Japan Policy Research Institute, ably represented this point of view in his 1982 book *MITI and the Japanese Miracle: The Growth of Industrial Policy*, writing that "Japan's postwar economic triumph—that is, the unprecedented economic growth that has made Japan the second most productive open economy that has ever existed—is the best example of a state-guided market system currently available."

But more recently the Japanese system has also met with a fair amount of criticism, and in *Divided Sun*, Scott Callon, the chief market strategist of Bankers Trust Asia Securities in Tokyo, weighs in on that side of the argument. He notes that in the case of Japan, government's ability to combine cooperation with competition has seriously disintegrated—that in fact the process of disintegration was already under way when glowing assessments like Johnson's appeared. "The elaborate structures to promote cooperation that appear in Japanese high-tech consortia are often nothing but a public show: seemingly cooperative institutions mask an underlying reality of fierce competition and conflict," he says. And the evidence he uses to support this charge comes from four different Ministry of International Trade and Industry (MITI)



case studies extending from 1975 to the present time: the Supercomputer Consortium; the VLSI (Very Large-Scale Integrated Circuits) Consortium, which concerns itself with advanced semiconductor technologies; the Fifth Generation Consortium, which is designed to make artificial intelligence breakthroughs; and TRON (The Realtime Operating System Nucleus), an ambitious bid to revolutionize personal computers.

Callon concludes that cooperation absolutely cannot be forced upon companies that compete in the industrial sector. One of the most vivid demonstrations of what can happen if it is occurred when engineers from NEC and Hitachi came to a Fujitsu research facility to work together on the MITI Supercomputer Consortium, he reports. The NEC and Hitachi engineers found that they were forbidden to use the bus that connects the research facility with the train station lest they overhear important Fujitsu trade secrets. For similar reasons, they were instructed to stay in their respective rooms, unless they had to go to the bathroom. More significantly, the high degree of cooperation the project required meant that Fujitsu had to provide detailed, highly proprietary information on an existing product to NEC and Hitachi, which was something "it ultimately could not bring itself to do."

The author points out, furthermore, that when cooperation does work for companies in a MITI-sponsored consortium, it is because competition among them is not a major difficulty anyway. Of all the high-tech case studies in *Divided Sun*, the VLSI Consortium is arguably the only one that can be considered even a partial success, and the main reason for this, he says, is that MITI provided the Japanese firms in it with large-scale financial subsidies at a time when they were in a financial crisis and faced increased technological competition from IBM. Under the circumstances, the companies were willing to overlook their corporate differences and work together. Such a situation is unlikely to occur today: ever since the 1980s, when Japan became a leading technology-driven economy on par with the United States, it has been clear to Japanese high-tech firms that their biggest competitors are one another.

A Conflict of Goals

One more lesson Callon draws from his observations is that a conflict of goals and institutional priorities is to be expected when private firms and government agencies become partners. The difficulty is particularly evident in the experience of the Fifth Generation Consortium. Callon notes that the consortium placed a huge bet that general-purpose machines were too slow ever to be good engines for artificial intelligence (AI), and that it would be essential to build specialized computers to operate particular AI applications. As it happens, this was the opinion of the AI community in the United States as well, and a number of companies like Symbolics were founded to develop and build specialized AI computers. By the early 1980s, these companies had booming sales and profits.

Then, just a couple of years later, general-purpose Unix workstations arrived on the scene, built first by Apollo Com-

puter and later by Sun Microsystems. Unlike specialized AI computers, Unix workstations are relatively inexpensive to maintain, thanks chiefly to standardized parts, and their standardized operating system, AT&T's Unix, allows for ease of programming. As they rapidly gained market share, Japanese companies in the Fifth Generation Consortium, whose goal is to develop products that would actually sell in the marketplace, wanted to shift the focus of their research to these machines.

Unfortunately, however, government bureaucrats felt more comfortable sticking to the original technological roadmap, even if the route it designated contained no clear signs and was full of potholes. Why? Largely because it made better sense politically. As Callon puts it, "the [Japanese] taxpayers and Ministry of Finance, the guardian of the national purse, want to see something in metal in return for their yen." Specialized AI computers would satisfy that requirement; general-purpose workstations, whose technical sophistication is largely hidden away in their software, would not.

Moreover, MITI was feeling constrained by international trade pressures. The United States had traditionally restricted its complaints about Japan's industrial policy to the "elaborate web of tariffs, quotas, and regulatory approvals" that made selling products in that country so hard, but by the mid-1970s, American policymakers realized that Japanese imports into the United States were posing a problem as well. The value of the Japanese goods sold in the United States that was not balanced by U.S. goods sold in Japan took off around that time, doubling about every two years through the mid-1980s until it flattened out at $40 to 50 billion annually. A project like the Fifth Generation, which emphasized more futuristic research and therefore posed no immediate threat to U.S. trade, tended not to heighten tensions. This made it attractive to MITI, which, as a government agency, had to worry about such issues in a way that Japanese firms did not.

In fact, when MITI did decide to back a project that the United States would have found threatening, it made sure to cover its tracks. Unlike the VLSI, Supercomputer, and Fifth Generation projects, which are funded, organized, and managed primarily by MITI, the TRON Consortium is privately funded and organized, with limited MITI involvement. "TRON was deliberately aimed at creating something new, something Japanese, that would erode Microsoft's and Intel's lock on the world personal computer market," Callon explains. "As an official government effort, it would have been perceived as yet another example of unfair Japanese business/government alliance fostering competitive advantage and would have inflamed trade tensions with the United States, so it could absolutely not take the shape of the other three, official MITI consortia."

While Callon is an invaluable source of insight and historical perspective, his habit of equating the failure of high-tech consortia with the failure of Japanese industrial policy as a whole is annoying. Because of it, the most profound effect of *Divided Sun* may lie in providing ammunition for those who contrast the experience of the consortia with the success of U.S. firms like Microsoft and Intel, and go on from there to conclude that industrial policy does not work in general and certainly will not work for the United States.

The trouble with this line of reasoning is that it overlooks some significant and worthwhile components of Japanese industrial policy—particularly in "sunset industries" like shipbuilding, coal, and textiles and in the relatively low-tech consumer electronics sector, which encompasses such widely used items as faxes and VCRs. In these areas, where little, if any, new ground is being broken, cutting-edge research is not nearly as important as it is in the realms that have spawned the consortia Callon describes. As a result, policy initiatives can be relatively inexpensive, and success is far less likely to depend on a single product or technology.

Put simply, the stakes are lower, so that cooperation among firms is more feasible, and MITI and related agencies like the Japan External Trade Organization (JETRO) have worked well to exploit that possibility. Their efforts are particularly visible in emerging Asian economies like Thailand, Malaysia, and Indonesia, where JETRO offices, in cooperation with Mitsui, Mitsubishi, and others, often serve as one-stop information centers, providing technical assistance, investment advice, and joint-venture leads to fellow Japanese firms.

A mere recognition of this success could help make the industrial policy debate much more meaningful and substantive, yet as observers continue to swing from the notion that MITI can do nothing wrong to the similarly simple-minded notion that MITI can do nothing right, no such recognition seems

imminent. U.S. economists appear not to have even grasped the key fact that MITI, while hardly omnipotent, nevertheless has much more clout in Japan than, say, the U.S. Department of Commerce and the U.S. trade representative have in the United States. The Sun, in other words, may indeed be divided—and Callon may have done a commendable job of showing why and how it is divided—but there are also some ways in which it is whole. And until analysts take a look at them, our understanding of what industrial policy can and cannot do will remain sadly limited.■

JACOB PARK is a former policy analyst in the Global Environmental Affairs Office of Japan's Ministry of International Trade and Industry.

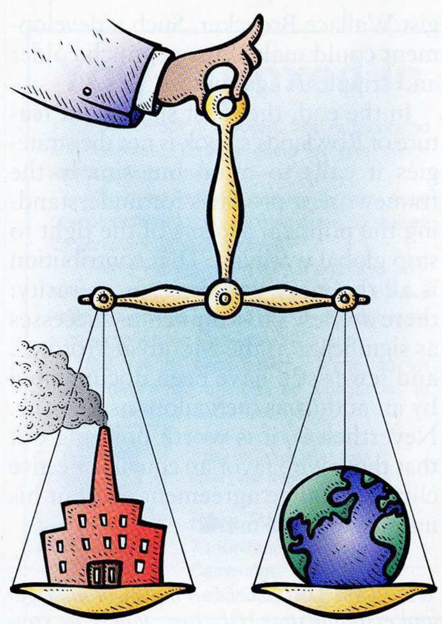
BOOKS

GEARING UP TO FIGHT GLOBAL WARMING

The Politics of Global Atmospheric Change
by Ian H. Rowlands
Manchester University Press, $29.95

BY WILLIAM DRISCOLL

A MERE 16 years after the theoretical finding that chlorofluorocarbons (CFCs) can destroy stratospheric ozone, a global agreement to phase out CFC production went into effect. By contrast, the theory that rising levels of atmospheric carbon dioxide and other greenhouse gases would cause global warming was first advanced a century ago, but has not yet been followed by effective global action. In *The Politics of Global Atmospheric Change*, Ian H. Rowlands, a political scientist at the London School of Economics and Political Science, reflects on why this is so. Exactly what



would it take, he asks, to achieve an effective global agreement to stabilize the climate?

First, he says, scientists have to agree that a problem does in fact exist, and they have to reach consensus on what is causing it. Second, all key actors have to perceive that an agreement is in their interest—including developing nations, whose most pressing concern is often economic growth, not pollution control. Rowlands notes that both these elements were at work in the effort to phase out CFCs.

Significantly, the first of Rowlands's preconditions for an effective climate change agreement has now been met: the scientific working group of the Intergovernmental Panel on Climate Change has concluded that the global mean surface air temperature has increased, and that human-caused greenhouse gas emissions have contributed to that rise. However, the other precondition Rowlands outlines—a general feeling among nations that an agreement would be in their interest—may be harder to fulfill for climate change than it was for ozone protection.

The main problem is that the costs of limiting greenhouse gas emissions could be much higher than the costs of phasing out CFCs, for developed and developing countries alike. Against these costs must be weighed the benefits of climate stability, which, for most of the world, are uncertain. So far only island nations threatened by rising sea levels have strenuously called for substantial cuts in greenhouse gas emissions. Yet if emissions reductions were viewed from a broader perspective, we might determine that costs will be lower and benefits will be higher than they now appear.

A Political Feedback Loop

The costs of reducing emissions will decline with technological advances in areas such as renewable energy. These advances depend on the level of research and development, which in turn depends largely on political signals. Here Rowlands's book is particularly instructive. The history of CFC regulation, as he describes it, illustrates the importance of the feedback loop between political actors and manufacturing firms.

Rowlands shows that chemical companies began looking for CFC substitutes in the late 1970s, after chemists Sherwood Rowland and Mario Molina published their theoretical finding that CFCs destroy ozone, prompting the United States and Europe to limit the use of such chemicals in aerosols. The companies opposed a total CFC ban, however, and in the early 1980s, when neither the United States nor Europe issued further regulations, they significantly reduced their research.

It was not until an ozone hole was discovered over Antarctica in 1985 that chemical companies relinquished their opposition to a ban on CFCs and acknowledged that substitutes were possible. The discovery of the ozone hole suggested that strong political action to halt production of CFCs might be imminent, and fortunately, the chemical industry no longer felt compelled to oppose such action: although companies had recently reduced their research, the studies on CFC substitutes initiated years earlier had produced encouraging results. Once the perceived benefits of CFC controls had risen high enough—and the perceived costs had fallen low enough—the way

was clear for the 1987 Montreal Protocol and subsequent amendments aimed at phasing out production of CFCs and other ozone-depleting substances.

For greenhouse gas emissions, too, the perceived costs of reductions may decline substantially if political signals prompt more intensive research. And a better understanding of the benefits of a stable climate might very well help generate those signals. Current assessments of what we have to gain from keeping the climate stable address only some sectors in some countries, and fail to consider the advantages of heading off the more frequent droughts, floods, and storms that global warming may induce. Nor do they consider the potential for extreme changes, such as a shift in direction in the warm water "conveyor" in the North Atlantic, a phenomenon postulated by Columbia University geologist Wallace Broecker. Such a development could make Europe much colder and cripple its agriculture.

In the end, the most significant feature of Rowlands's book is not the strategies it calls to mind but simply the framework it provides for understanding the political aspects of the fight to stop global warming. That contribution is all the more welcome for its rarity: there are few environmental successes as significant as the Montreal Protocol, and fewer still have been documented by an author as meticulous as this one. Nevertheless, it is worth pointing out that those who favor an equally effective climate-change agreement can put his insights to good use.■

WILLIAM DRISCOLL is a project manager and economist at ICF, Inc., where he conducts analyses of climate-change issues.

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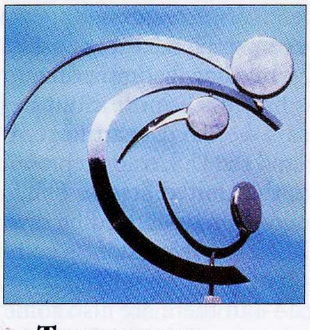

WHERE TECHNOLOGY AND NATURE MERGE

Dennis Normile's examination of Kiyoyuki Kikutake's "Responsive Sculpture" (*TR August/September 1996*) prompted me to think about humanity's relationship with nature. For centuries, the Chinese have questioned whether people should conquer or follow nature. As technology advances and some of its applications adversely affect nature, this question will become increasingly important.

As an engineer-turned-artist, Kikutake appears to have a heightened motivation in seeking man's harmony with nature. Through technology, he makes us more aware of nature, whether it's the wind in autumn or the sun in summer. Through technology, he also makes us more aware of our assault on nature (such as through growing emissions of carbon dioxide). Through his sculpture, he comments on our failure in building cities: too often we are creating urban fortresses rather than livable communities.

What impressed me most about Kikutake's "Garden of Light" is that as one approaches it and the wind blows, quiet music begins to chime and water mysteriously begins to drip down the sculpture's "legs." Here, people, nature, art, and technology magically appear to have reached some sense of balance. Kikutake's sculptures challenge all of us to search for that same sense of balance between man and nature, and the same magical fusion of art and technology.

WEIMING LU
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COOL OR LOCO?

Unlike senior editor David Brittan in "Anagrams Made Easy" (*TR July 1996*), I am not surprised that software could not turn up an apt anagram for *Technology Review*. With patience and wit, I arranged the following: "We? Everything cool!" and "We? Everything loco!" Take your pick.

News items have prompted me to come up with the following:

Prime Minister Benjamin Netanyahu: Jimminy! The man beat Peres in a run-in!

Secretary of Commerce Mickey Kantor: My occ. is economy, free-market tracker.

Clinton versus Dole: Select U.S. lord in Nov.

I received a PhD in organic chemistry from MIT in 1961. During hours of tediously tending to a homemade gas chromatograph as it spit out precious droplets, wordplay (mostly crossword puzzles in the early days) kept me awake and sane.

MARY J. HAZARD
Rochester, N.Y.

A SERIOUS INSTRUMENT

Herb Brody's "Wired Science" (*TR October 1996*) gave a splendid overview of the Internet's vast scientific potential. As scientists working toward that potential, we have encountered a major psychological barrier not mentioned in the article: the public's view that the Internet is a "hobby" for scientists to tinker with in their spare time. Although a global library has been the dream of scholars since the days of Nineveh and Alexandria, the Internet's creation is not considered on par with teaching and research. Witness the struggle of physicist Paul Ginsparg to obtain funding for an online archive of physics papers. The perception of the Internet will change only when people take to heart the message of the final paragraph and realize that the Web itself is an instrument for research.

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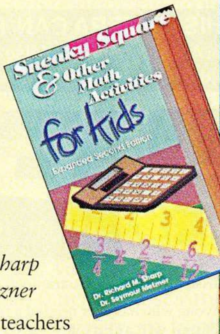

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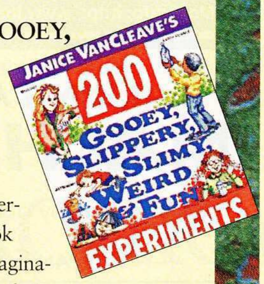

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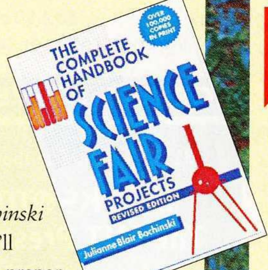

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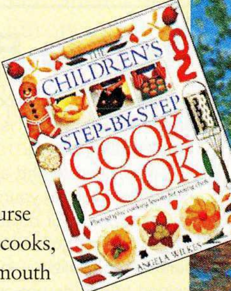

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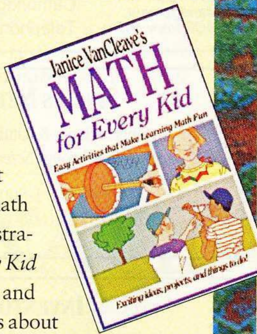

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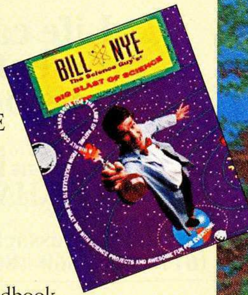

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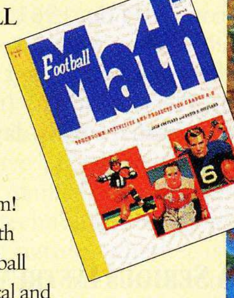

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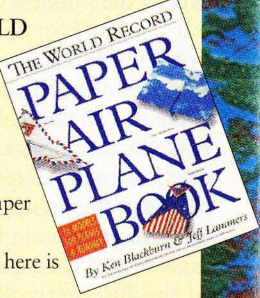

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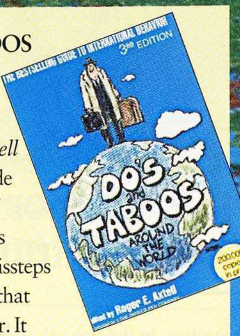

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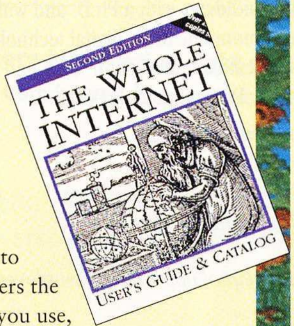

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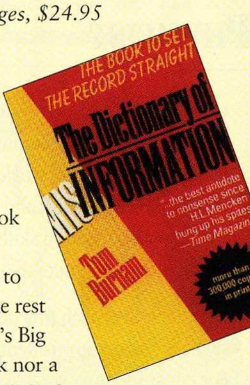

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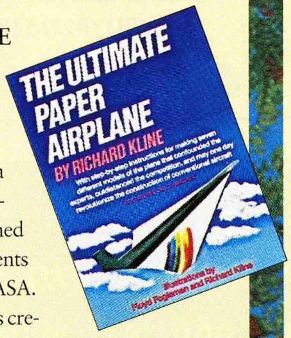

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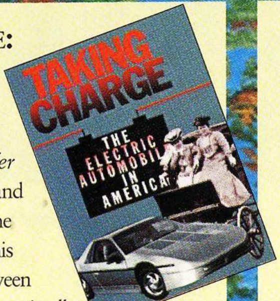

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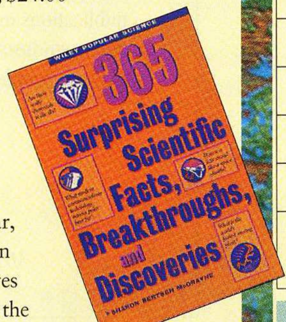

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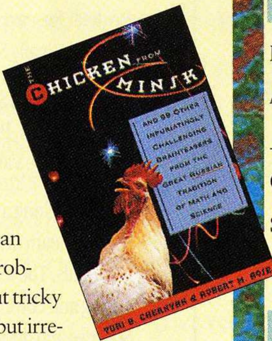

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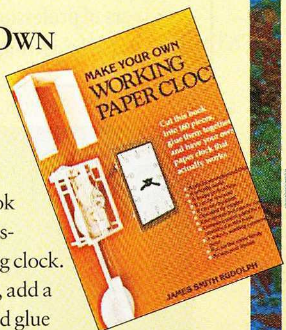

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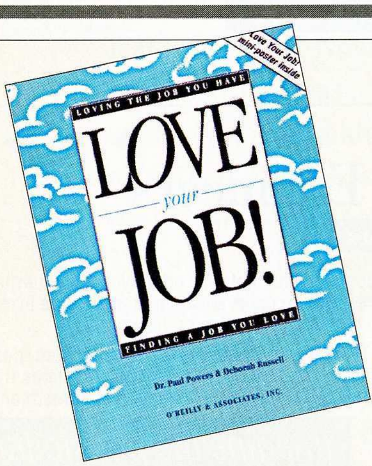

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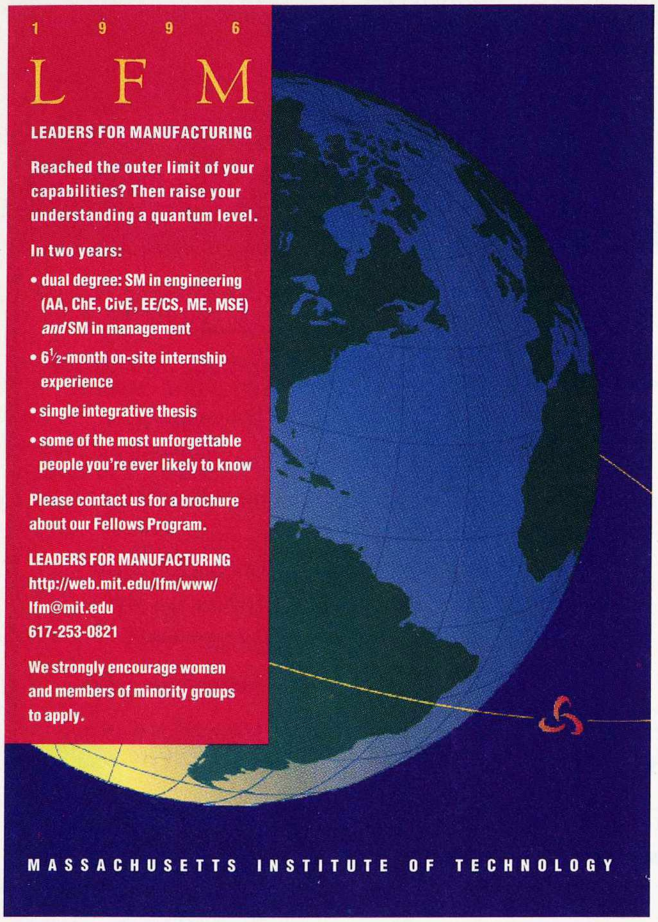

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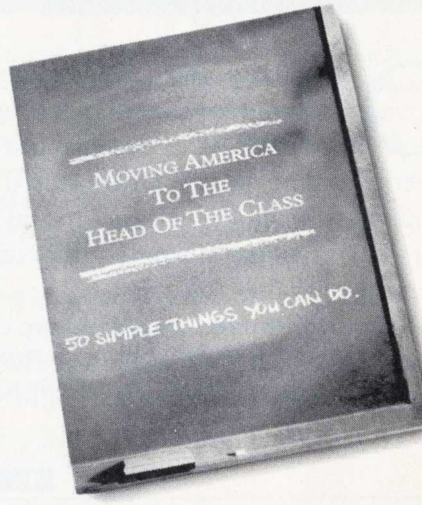

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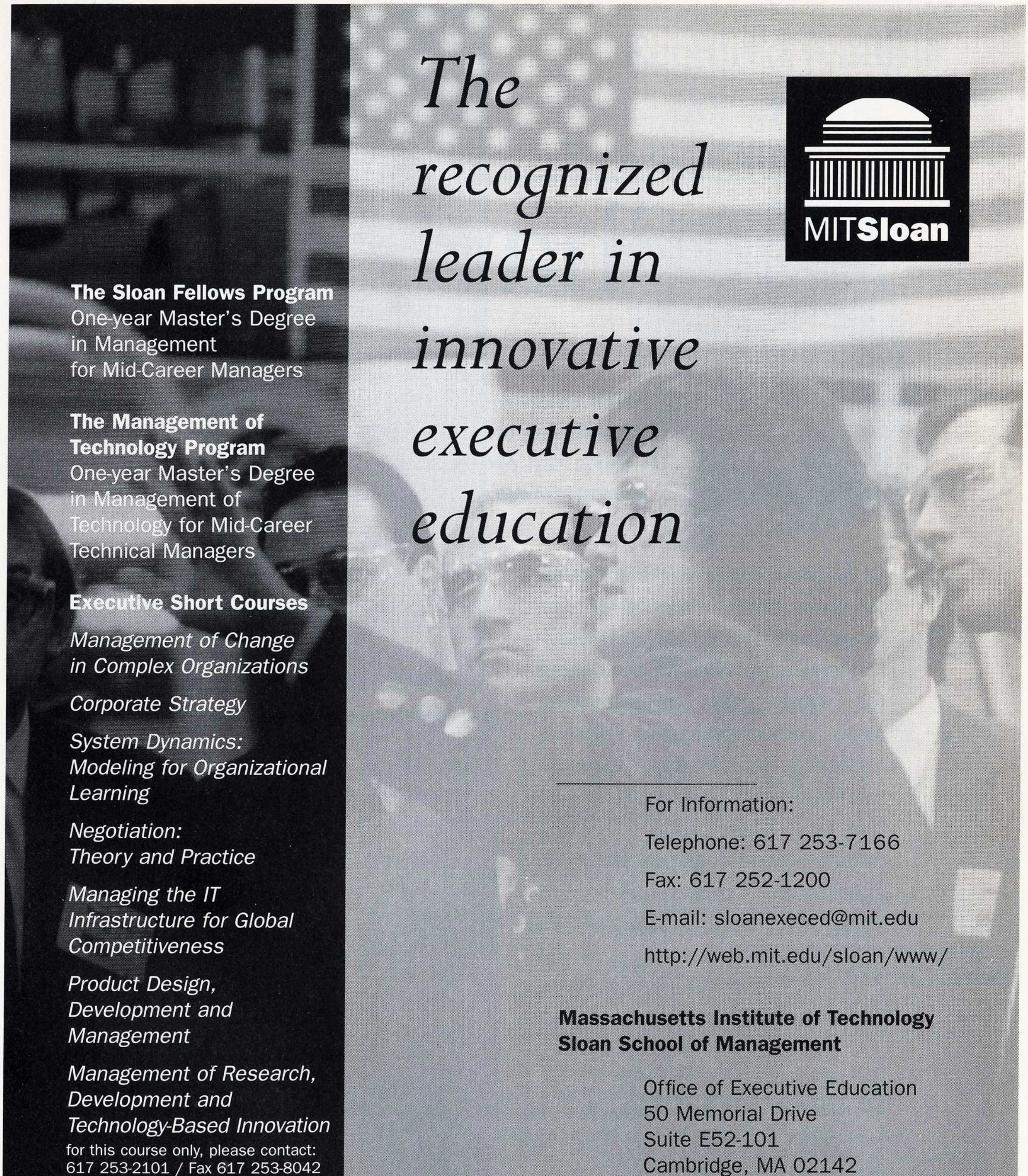
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